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The Full Cost of Electricity (FCe-)

Quantifying Diversity of Electricity Generation in the U.S.

PART OF A SERIES OF WHITE PAPERS

TEXAS
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THE FULL COST OF ELECTRICITY is an interdisciplinary initiative of the Energy Institute of the University of Texas to identify and quantify the full-system cost of electric power generation and delivery – from the power plant to the wall socket. The purpose is to inform public policy discourse with comprehensive, rigorous and impartial analysis.

The generation of electric power and the infrastructure that delivers it is in the midst of dramatic and rapid change. Since 2000, declining renewable energy costs, stringent emissions standards, low-priced natural gas (post-2008), competitive electricity markets, and a host of technological innovations promise to forever change the landscape of an industry that has remained static for decades. Heightened awareness of newfound options available to consumers has injected yet another element to the policy debate surrounding these transformative changes, moving it beyond utility boardrooms and legislative hearing rooms to everyday living rooms.

The Full Cost of Electricity (FCe-) study employs a holistic approach to thoroughly examine the key factors affecting the *total direct and indirect costs* of generating and delivering electricity. As an interdisciplinary project, the FCe- synthesizes the expert analysis and different perspectives of faculty across the UT Austin campus, from engineering, economics, law, and policy. In addition to producing authoritative white papers that provide comprehensive assessment and analysis of various electric power system options, the study team developed online calculators that allow policymakers and other stakeholders, including the public, to estimate the cost implications of potential policy actions. A framework of the research initiative, and a list of research participants and project sponsors are also available on the Energy Institute website: energy.utexas.edu

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This paper is one in a series of Full Cost of Electricity white papers that examine particular aspects of the electricity system.

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Quantifying Diversity of Electricity Generation in the U.S.

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ABSTRACT:

Often current energy and environmental policies follow the paradigm of focusing on getting the prices right within a market system. The general argument is that such a focus would lead to socially optimal outcomes in the long run. An important weakness of this paradigm is that it is not robust to major or rapid unforeseen shifts in our knowledge about the benefits and costs of the production system. At the societal level, preparing for such shifts inherently requires a different approach than a focus only on prices. It requires an adaptive, systemic approach that is open to the possibility that assumptions underlying today's markets and technologies may turn out to be quite different as more experience and knowledge is gained over time (and sometimes quite rapidly). The evolutionary economics approach, with its focus on diversity to enhance long-term resilience, is one such alternative approach to neoclassical economic approaches.

Based on these approaches, in this paper we quantify diversity of the electricity sector in the U.S. using primary energy source data from the U.S. Energy Information Agency (EIA). We use the Shannon-Wiener Index, Simpson Index, and Stirling Index to compare the diversity of each state's electricity system and find that the major drivers of diversity change have been the result of wind and natural gas adoption.

INTRODUCTION

How should societies allocate their resources to ensure economic growth and development, while being sustainable and resilient? Neoclassical economics offers a broad response, contending that optimal allocation of resources through markets at all junctures should do the trick. But often there are externalities – factors that are not priced in goods and services transacted in the market – associated with the normal functioning of the economic system. For externalities too, the standard response in the neoclassical approach is to internalize them through *ad hoc* price fixes *once the externalities are discovered*. For example, in the case of local air pollution this involves putting a price on emissions of pollutants such as sulfur dioxide, particulate matter, etc. However, one criticism of such approaches is that they assume too much information availability and are built upon relatively rigid trajectories about the future technological state and the relevant knowledge space that inform policy design, whereas in reality *unknown* impacts of past technologies and technological change continuously surprise us. Overall, these arguments contend that in the long run policies relying entirely on markets and prices could lock us into suboptimal situations, thus a new way of approaching sustainable development is needed.

As an alternative to the neoclassical approach, and partly inspired by the biological and ecological sciences, a strand of literature has emerged over the past couple of decades arguing that *diversity* is one of the central features for achieving long-term resilience even in socioeconomic systems. In this view, while price signals try to alleviate known system issues (i.e., *after* externalities have been discovered), diversity can help mitigate risks completely unknown to society now. Thus, broadly speaking, diversification "is what we can do when we don't know what we don't know" (Stirling 2010).

The purpose of this study is not to address the debate between neoclassical and evolutionary economic approaches. Rather we seek to address a much simpler empirical question: from a historical perspective, what does diversity look like in the U.S. electricity sector? Besides some thoughtful broad analysis (Hanser and Graves 2007), we found the literature to be largely silent on this question, especially from an empirical perspective. Accordingly, the purpose of this paper is to set an empirically-derived diversity baseline for the electricity sector in the U.S. and to qualitatively assess what has driven changes in diversity. We quantify diversity for each state in the U.S. based on the primary energy sources (PESs) used to generate electricity, offering a systematic U.S.-wide quantification of diversity and its evolution in the electricity generation sector. As older generation plants begin to retire, new generation technologies mature, and local and global environmental impacts of electricity generation and use become more prominent, we hope that our analysis would provide an empirical basis for considering how diversity might play a role in our energy infrastructure moving forward. ■

BACKGROUND AND RELATED LITERATURE

When resilience becomes the focus, scholars who emphasize the ecological, evolutionary, and system dynamics aspects of economic systems contend that just markets and price signals are insufficient and other system properties, such as thresholds (for transitions, tipping points, etc.) and diversity, become highly relevant (Rammel and van den Bergh 2003, Perrings 2006). While acknowledging the importance of price signaling from an economic perspective, Perrings (2006) points to the shortsighted actions market signals can force firms to make. For example, in some cases, market signals reward actions taken after a disaster rather than rewarding more economical preventative measures prior to a disaster (Perrings 2006). Perrings offers two strategies to help decision makers create policies that promote resilience and sustainability. First, it is important to understand system dynamics when implementing sustainable management system to prevent unwanted outcomes when market controls are implemented. Complete understanding, however, is difficult to obtain, thus policies and program implementation must continue to "experiment" with the system to keep learning about its internal dynamics and interactions with external factors. The second strategy is that of diversification. In ecology, diversity builds in functional redundancy that can help under various conditions, even when those conditions are unanticipated. Likewise, diversity can also help build redundancy in socioeconomic systems under various social and environmental conditions (Perrings 2006).

Rammel and van den Bergh (2003) further discuss the benefits of diversity as it pertains to socioeconomic systems. First, diversity can enhance adaptive flexibility, i.e., the ability to adapt to changing conditions. That is because diversity in the system could help maintain functions that may be deemed unimportant under one set of social and environmental conditions but may become important and necessary as those underlying conditions change. Second, diversity can help mitigate path-dependence and lock-in. Most new technologies are based on existing technologies: "Technologies are born from technologies" (Arthur 2009). This creates a certain trajectory for technology development (Dosi 1982); as development along a certain technological trajectory deepens, other alternative trajectories become distant and less feasible, thereby giving rise to path-dependence. While not problematic under normal conditions, path-dependence can make altering the technological trajectory difficult at best and impossible at worst when such a need arises because of fundamentally new important information learned in the system. Path-dependence can be mitigated, however, through policies that focus on diversity to help promote development of technologies placed along different technological trajectories (Nill and Kemp 2009). Third, diversity can help address unknown risks. Since socioeconomic systems are complex and evolving, many risks are unpredictable. A diversified system could help with adapting to these unknown risks (Rammel and van den Bergh 2003). Stirling (1994) argues that diversification can be used as the main response against ignorance. As Perrings (2006) states that decision makers should strive for greater understanding of system dynamics and diversity, Stirling (1994) contends that diversification could fill in the blanks that understanding leaves out. ■

DIVERSITY AND RESILIENCE IN THE ELECTRICITY SECTOR

Energy security is often defined as "availability of energy *at all times* [emphasis added] in various forms in sufficient quantities and at affordable prices" (Umbach 2004). Rather than focusing on long-term resilience, decision makers often find themselves grappling with myriad near-term and known threats to energy security such as inefficient markets, poor planning, geopolitical unrest, dwindling fuel stocks, etc. These threats and their solutions are not trivial issues and play a major role in ensuring reliability of the system. However, addressing them is no substitute for long-term resilience planning, which entails dealing with unknown risks. Diversification can, therefore, play a complementary role for ensuring energy security by addressing unknown threats (Stirling 2010).

Diversification of the electricity system can be very complicated due to the complex nature of the system. Utilities must supply reliability, quick response to changes in supply and demand at multiple locations, and increasingly cleaner power sources. Electricity systems also require large amounts of capital for construction of generators and other infrastructure that requires long time horizons, involving financial institutions, regulators, utilities and other firms, and end-users across multiple sectors. As a result of this complexity, diversity may be thought of being applicable in a variety of ways at multiple levels of planning (Hanser and Graves 2007). Diversification can be applied to a number of factors such as technologies, manufacturers and suppliers, PESs, and workforce. Limiting ourselves to any one factor misses the point of diversification (Stirling 2010). However, as these systems are very complicated, this study aspires only to present a quantification of diversification and qualitatively assessing how diversification has changed over the years for states and regional entities in the U.S. We limit the scope to applying the methodology to PESs only, rather than the multitude of other relevant factors. Diversity in the electricity sector is regularly limited to only PESs since PESs are often used as a proxy to capture differences in flexibility of operation, intermittency of generation, environmental effects, technology maturity, supply chain characteristics, and others (Cooke et al. 2013).

PITFALLS OF ADOPTING DIVERSITY INDICES

Similar to a strictly neoclassical approach, a more evolutionary approach also has its own set of challenges. Diversity tends to cost more and may not pass muster in a traditional cost-benefit approach. That is because while lock-in and path-dependence could reduce adaptability and resilience in the long-run, they also contribute to "economies of scale and scope, cumulative technological change, learning, network externalities, and complementary production factors" (Rammel and van den Bergh 2003).

Implementing diversity can also be challenging because of subjectivities involved in the process. One issue with putting diversity to practice is that often options are prioritized based on desirable traits and selective distinction and not necessarily on purely objective constructs of diversity (Yoshizawa et al. 2009; Stirling 2007). Stirling points to three traits of diversity: variety, balance, and disparity. Variety refers to the number of options. Balance refers to how proportionally reliant a system is on a particular option. Disparity refers to how different each option is (Stirling 1994; Stirling 2007; Stirling 2010; Cooke 2013). In all three diversity traits there is a hint of subjectivity, although more in some traits than others (Cooke 2013; Stirling 1994).

DIVERSITY CALCULATION METHODS

There are multiple *diversity indices* for calculating the diversity of various systems. These indices generally consider some portion of the three attributes of diversity: variety, balance, and disparity (Cooke 2013, Stirling 1994). For example, the UK currently uses the Shannon-Wiener Index to measure diversity of the electricity sector in the UK. The Shannon-Wiener Index – originally introduced by Claude Shannon to quantify information uncertainty – is given by the following equation:

$$H = -\sum_{i=1}^{n}(p_i \ln p_i) \,,$$

where n is the number of options or categories (i.e., variety) and p_i is the proportion of option i among all options (i.e., balance). The quantity H is also known as the information entropy. The corresponding diversity is calculated as e^H. The maximum value of the Shannon-Wiener Index increases with increasing n and (for a given number of categories) occurs when $p_i = 1/n$ for all i.

The Shannon-Wiener Index places emphasis on variety and balance, but, compared to the other indices, it gives greater weight to the existence of even small contributors (Cooke et al. 2013). (As explained later, in this study, each state's maximum possible n is 11, corresponding to the various PES categories we employ.) Thus even if one of the PESs only produces a small amount of electricity (i.e., has a small p), it can still contribute non-trivially to the overall diversity.

In ecology the Simpson Index ($\sum_{i=1}^{n} p_i^2$)is used to measure the degree of concentration when individuals are categorized into different types or categories. Squaring p_i gives more emphasis to categories of i with larger proportions. (The Herfindahl-Hirschman Index (HHI), a measure of market concentration commonly used in economics, is essentially the same as the Simpson Index.) To measure diversity, the original Simpson Index is inverted:

$$\frac{1}{\sum_{i=1}^{n}(p_i{}^2)} \,.$$

The modified Simpson Index (inverse of the original Simpson Index, noted simply as the "Simpson Index" from this point on in the paper) places greater influence on the balance of a system to determine the overall diversity of a system. As with the Shannon-Wiener Index, the Simpson Index also only considers variety and balance. Thus both the Shannon-Wiener Index and Simpson Index leave out the disparity attribute of diversity and, in so doing, assume that all options are equally disparate (Stirling 2010).

The Stirling Index combines variety, balance, and disparity into one measure:

$$\sum_{i,j=1, i \neq j}^{N} \left(d_{ij} p_i p_j\right) .$$

Disparity is captured in the term d_{ij}. Disparity can vary depending on what measures are used to determine the difference between two categories, i and j. The disparity term is generally determined based on distances on a normalized scale. It is common to determine d_{ij} through expert elicitation. Experts, however, will not always agree on what they consider important. As a result, calculating disparity involves some subjectivity, thus can provide perspective on various portfolio options depending upon beliefs about disparity (Stirling 2010, Yoshizawa et al. 2009). ■

METHODS AND DATA

In this paper we compare the diversity of electricity systems based on the PESs used to generate electricity. To compare the diversity, we calculated the Shannon-Wiener, Simpson, and Stirling indices, similar to the approach in Cooke et al. (2013), for all states and regional entities in the U.S. The purpose for using three different indices is to compare how different methods for diversity calculation result in different diversity outcomes using the same inputs. Keeping track of all three indices can help tease out additional information about each portfolio of options.

The calculated Stirling Index was multiplied by 30 in this study to bring the index values into a comparable range with the Shannon-Wiener Index and Simpson Index (0 to 6). It is important to note that the index values themselves are not the point. Rather, it is the relative differences in index values over time and between states that matters in our analysis. As such, multiplying the index value by a constant does not alter the qualitative insights that emerge from this study.

In this paper we did not independently determine disparity between primary energy sources (PES). Instead, we turned to Yoshizawa et al. (2009). The experts in the Yoshizawa et al. (2009) study represented various interest groups including academia, government, and private sector. We used the disparity numbers determined for a UK senior academic energy economist who cared about engineering cost, climate change impact, long-run security, and public acceptability. Our choice was based primarily on the assumption that among the three experts the academic expert's beliefs represented a more stable and balanced view of the underlying technological disparities, since government and private sector priorities (and beliefs) are prone to large swings depending upon the political and business environment. Ideally, the disparity chart should be based on expert elicitation from various U.S. electricity experts, but we leave that for future research. The UK economist's disparity chart is shown in Figure 1.

From the dendrogram in Figure 1 we can infer that conventional thermal sources (nuclear, biomass, coal with carbon capture, coal, oil, gas with carbon capture, and gas) and renewable sources of energy (solar PV, geothermal, wave – offshore, municipal/industrial waste, hydro, offshore wind, tidal stream, micro onshore wind,

FIGURE 1:

PES disparity chart for a UK senior academic energy economist. Source: Reproduced from Yoshizawa et al. (2009) with permission.

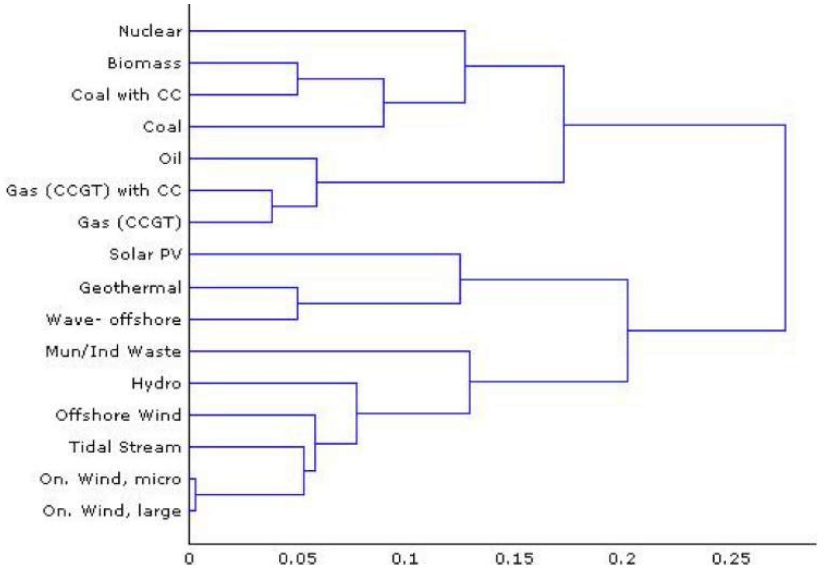

TABLE 1:

PES Disparity Matrix for a UK Senior Academic Energy Economist. Source: Data from Yoshizawa et al. 2009

	Coal	NG	Petro	Nuclear	Hydro	Geothermal	Solar/PV	Wind	Biomass	Muni/Ind Waste	Other
Coal	NA	0.171	0.171	0.126	0.271	0.271	0.271	0.271	0.088	0.271	0.1355
NG	0.171	NA	0.059	0.171	0.271	0.271	0.271	0.271	0.171	0.271	0.1355
Petro	0.171	0.059	NA	0.171	0.271	0.271	0.271	0.271	0.171	0.271	0.1355
Nuclear	0.126	0.171	0.171	NA	0.271	0.271	0.271	0.271	0.126	0.271	0.1355
Hydro	0.271	0.271	0.271	0.271	NA	0.199	0.199	0.077	0.271	0.128	0.1355
Geothermal	0.271	0.271	0.271	0.271	0.199	NA	0.123	0.199	0.271	0.199	0.1355
Solar/PV	0.271	0.271	0.271	0.271	0.199	0.123	NA	0.199	0.271	0.199	0.1355
Wind	0.271	0.271	0.271	0.271	0.077	0.199	0.199	NA	0.271	0.128	0.1355
Biomass	0.088	0.171	0.171	0.126	0.271	0.271	0.271	0.271	NA	0.271	0.1355
Muni/Ind Waste	0.271	0.271	0.271	0.271	0.128	0.199	0.199	0.128	0.271	NA	0.1355
Other	0.1355	0.1355	0.1355	0.1355	0.1355	0.1355	0.1355	0.1355	0.1355	0.1355	NA

Note that the PES options in the disparity matrix do not match the PES options in the disparity chart (Figure 1) because, as described next, we modified the chart to correspond to the data used in this study.

and large onshore wind) are the most disparate. The disparity between these two groups of energy sources is approximately 0.27, the max disparity value in this chart (given by the position along the x-axis where these two branches meet). From this chart, we created a disparity matrix.

To quantify the PES diversity of each state and regional entity, we used data from the U.S. Energy Information Agency (EIA) that separated net generation in each state based on the PESs used from 1990 to 2013. In this way, we were able to see how much a state or regional entity relied on PESs to generate electricity and how the proportion of those PESs used contributed to diversity. This data separated the energy sources into the following categories: coal, geothermal, conventional hydroelectric, natural gas, nuclear, other, other biomass, other gases, petroleum, pumped storage, solar thermal and photovoltaic (PV), wind, and wood and wood derivatives (EIA 2014). Since the disparity categories from Yoshizawa (2009) do not entirely match the EIA data, we made the following six assumptions: 1) Natural Gas is equivalent to Natural Gas Combined Cycle (NGCC), 2) Pumped Storage is equivalent to Hydroelectric, 3) Other Biomass is equivalent to Municipal/Industrial Waste, 4) Other Gases is equivalent to Natural Gas, 5) Wood and wood derivatives is equivalent to Biomass, and 6) Other is equivalent to midpoint of disparity values. The diversity matrix shown in Table 1 is based on these assumptions. Then, using the PES data described above and the disparity measures in Table 1, we calculate the Shannon-Wiener Index, Simpson Index, and Stirling Index for each U.S. state, regional entity, and the U.S. as a whole.

Since most states trade electricity across state borders, we aggregated states into their regional entities and calculated the index values for each regional entity. Since the entities generally do not follow state lines, we have included each state in the regional entity that covers the majority of the state. The regional entities are broken up as follows[1]: 1. Western Electricity Coordinating Council (WECC) – Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Utah, Washington, and Wyoming, 2. Midwest Regional Organization (MRO) – Iowa, North Dakota, South Dakota, Minnesota, Nebraska, and Wisconsin, 3. Southwest Power Pool Regional Entity (SPPRE) – Kansas and Oklahoma, 4. Southeast Reliability Corporation (SERC) – Alabama, Arkansas, Georgia, Illinois, Kentucky, Louisiana, Missouri, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia, 5. Reliability First Corporation (RFC) – D.C., Delaware, Indiana, Maryland, Michigan, New Jersey, Ohio, Pennsylvania, and West Virginia, and 6. Northeast Power Coordinating Council (NPCC) – Connecticut, Massachusetts, Maine, New Hampshire, New York, Rhode Island, and Vermont. ■

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[1] Note that we do not do separate calculations for the Electricity Reliability Council of Texas (ERCOT), since ERCOT is largely independent from the U.S. national grid. Moreover, the results for ERCOT are essentially the same as those that we report for Texas below, since ERCOT covers most (about 85%) of the electricity load in Texas.

RESULTS

Using the Shannon-Wiener Index, Simpson Index, and Stirling Index, we determined diversity trends of the PESs used to generate electricity in the U.S. in three ways: 1) diversity indices including all states, 2) diversity at the individual state level, and 3) diversity for regional entities. Overall, diversity has generally been increasing in all three categories as a result of increased adoption of natural gas and wind. Since each index places more emphasis on different aspects of diversity (variety, balance, and disparity), each index ranks the states somewhat differently in terms of relative diversity, highlighting how varying preferences for what is valued when measuring diversity contributes to the outcomes in aggregate diversity measures at the system level.

TRENDS IN DIVERSITY ACROSS ALL STATES

The distribution of all three diversity measures, the Shannon-Wiener Index, Simpson Index, and Stirling Index, are shown in Figure 2. In general, the median diversity index value has been increasing for all three indices. Additionally, the majority of states appear to be converging in diversity and the range between the 25th and 75th percentile is narrowing. The highest index value for each year appears to be decreasing in the Shannon-Wiener Index and the Simpson Index, indicating that diversity at the higher end has been decreasing for these two indices; in other words, more recently states at the higher end appear to be using fewer PESs and less balanced generation among those PESs. One of the primary reasons for this decrease can be attributed to the reduced use of coal and petroleum in favor of natural gas. New York and Massachusetts are great examples of this trend as can be seen from Figure 3 (see *Supplemental Information* for similar charts for each U.S. state).

Starting in 2005, natural gas began replacing petroleum and coal in New York (Figure 3, bottom left). From 2001, the same pattern can be seen in Massachusetts (Figure 3, bottom right). In both states, the Shannon-Wiener Index and Simpson Index decreased around the same time as the transition from coal and petroleum to natural gas (Figure 3, top figures). Interestingly, the Stirling Index did not decrease as noticeably.

The highest index values for each year for the Stirling Index appears to be relatively stable in Figure 2; however, there are more low-end outliers in the Stirling Index towards the end of the time period. This suggests that overall states may be balancing energy generation across more *disparate* sources over time, as evidenced by the tightening of the interquartile range for the Stirling Index since 2005 along with an upward trend in the median

FIGURE 2:

Distribution of Shannon-Wiener, Simpson, and Stirling Indices for all states from 1990 – 2013. Note that the y-axis scale is different for the Stirling Index (right panel) compared to the other two indices. The median is indicated by the solid bar in the box plot.

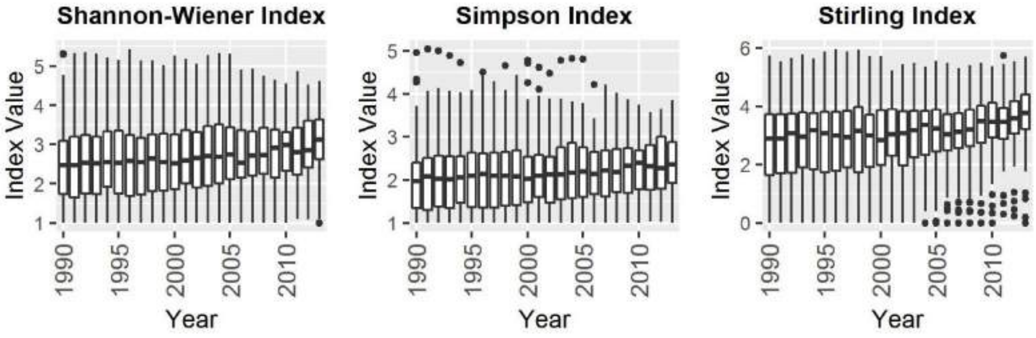
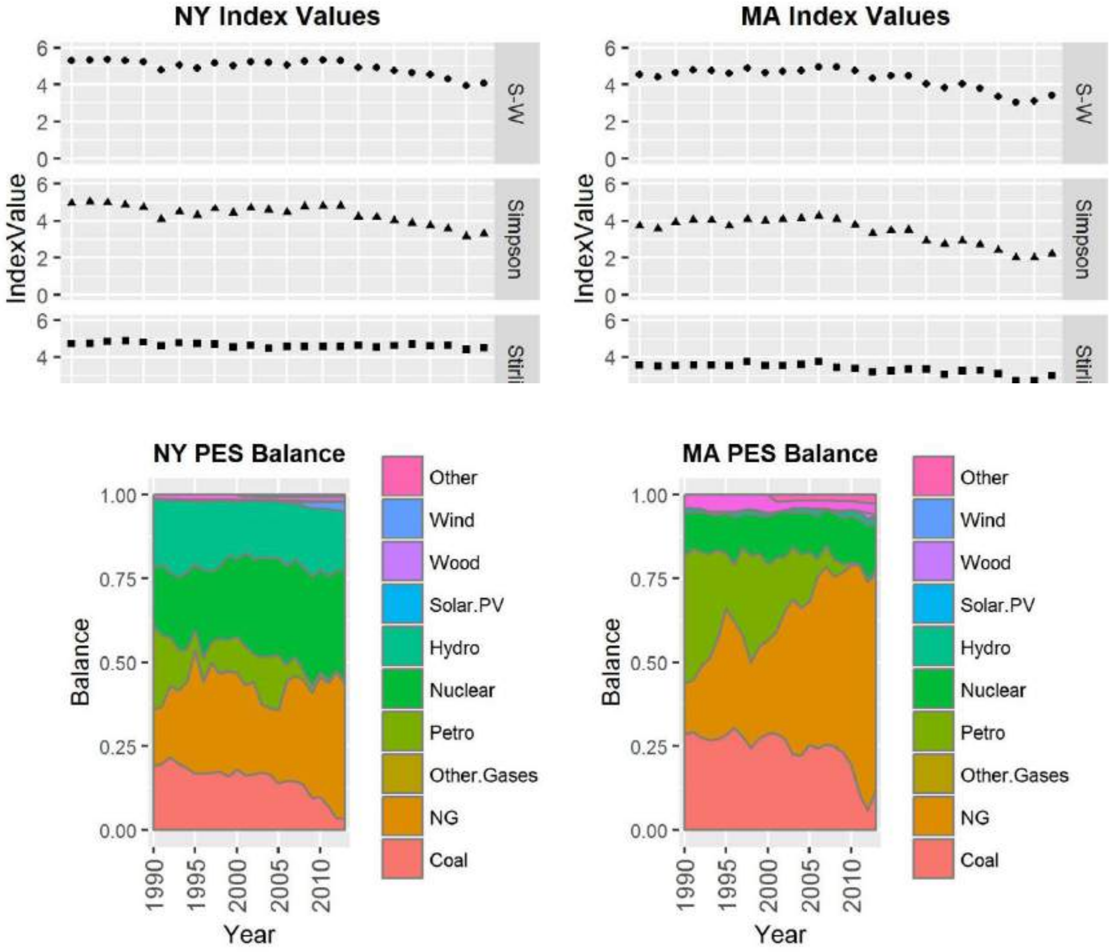


FIGURE 3

Diversity index and balance trends of New York and Massachusetts. The top two figures show the Shannon-Wiener, Simpson, and Stirling index values (top to bottom) from 1990 to 2013. The bottom two figures show the balance of PESs used to generate electricity in the states from 1990 to 2013.



value. One of the major drivers for increased diversity is the adoption of wind energy. Minnesota and Texas are great examples of how wind adoption has increased diversity in the states (Figure 4).

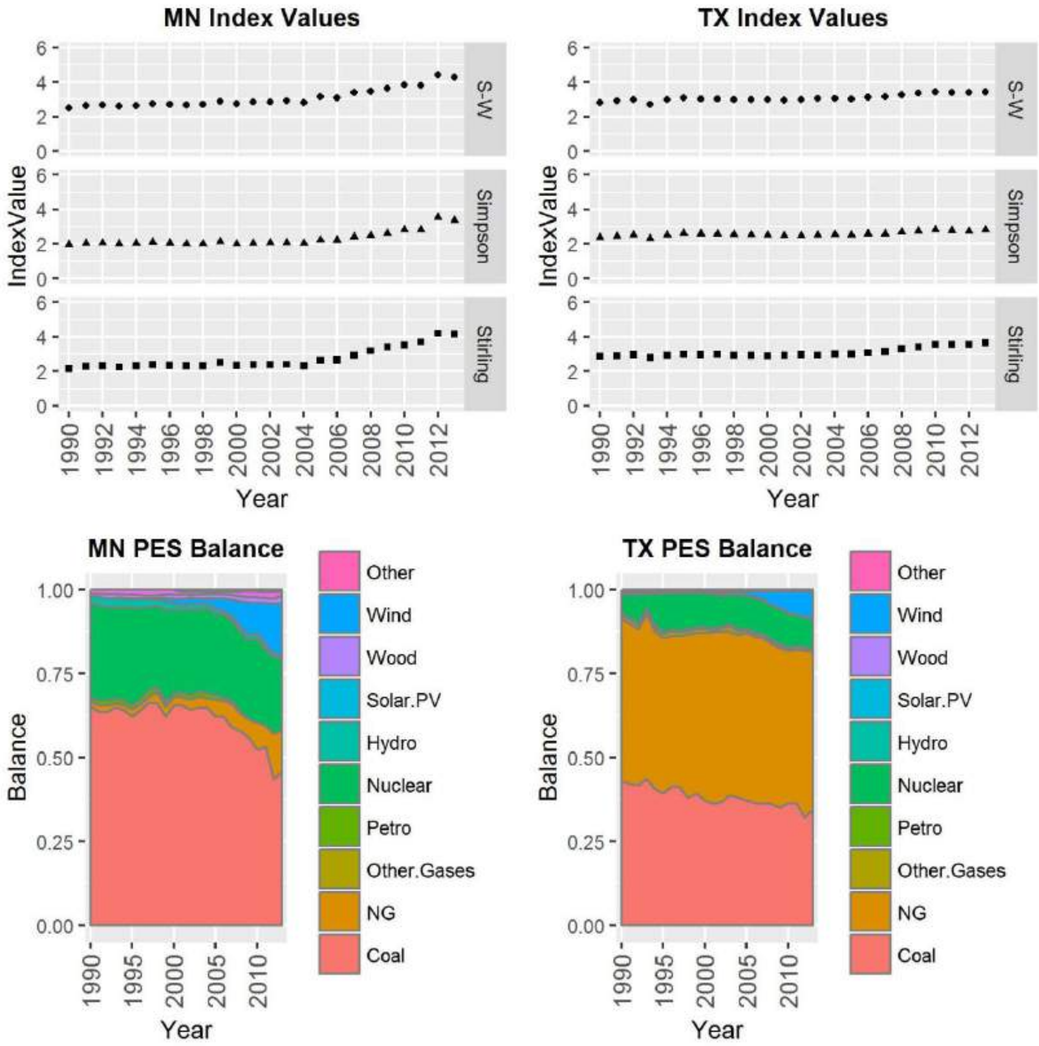
From about 2005, Minnesota and Texas both increased the proportion of electricity it generated from wind. Since wind was a relatively new PES and is highly disparate from incumbent PESs such as coal and natural gas, adoption of wind increased all three indices. We will see more examples of how natural gas and wind shaped the diversity of each state's generation portfolio.

TRENDS IN DIVERSITY AT THE STATE LEVEL

Figure 5 shows another macro view of diversity changes represented through state maps for the years 1990, 2001, and 2013.

FIGURE 4

Diversity index and balance trends of Minnesota and Texas. The top two figures show the Shannon-Wiener, Simpson, and Stirling index values (top to bottom) from 1990 to 2013. The bottom two figures show the balance of PESs used to generate electricity in the states from 1990 to 2013. from 1990 to 2013.



The shading of states for each of the three indices differs in some areas indicating that the three indices rank states differently. This is not surprising given that each index gives different weight to variety, balance, and disparity.

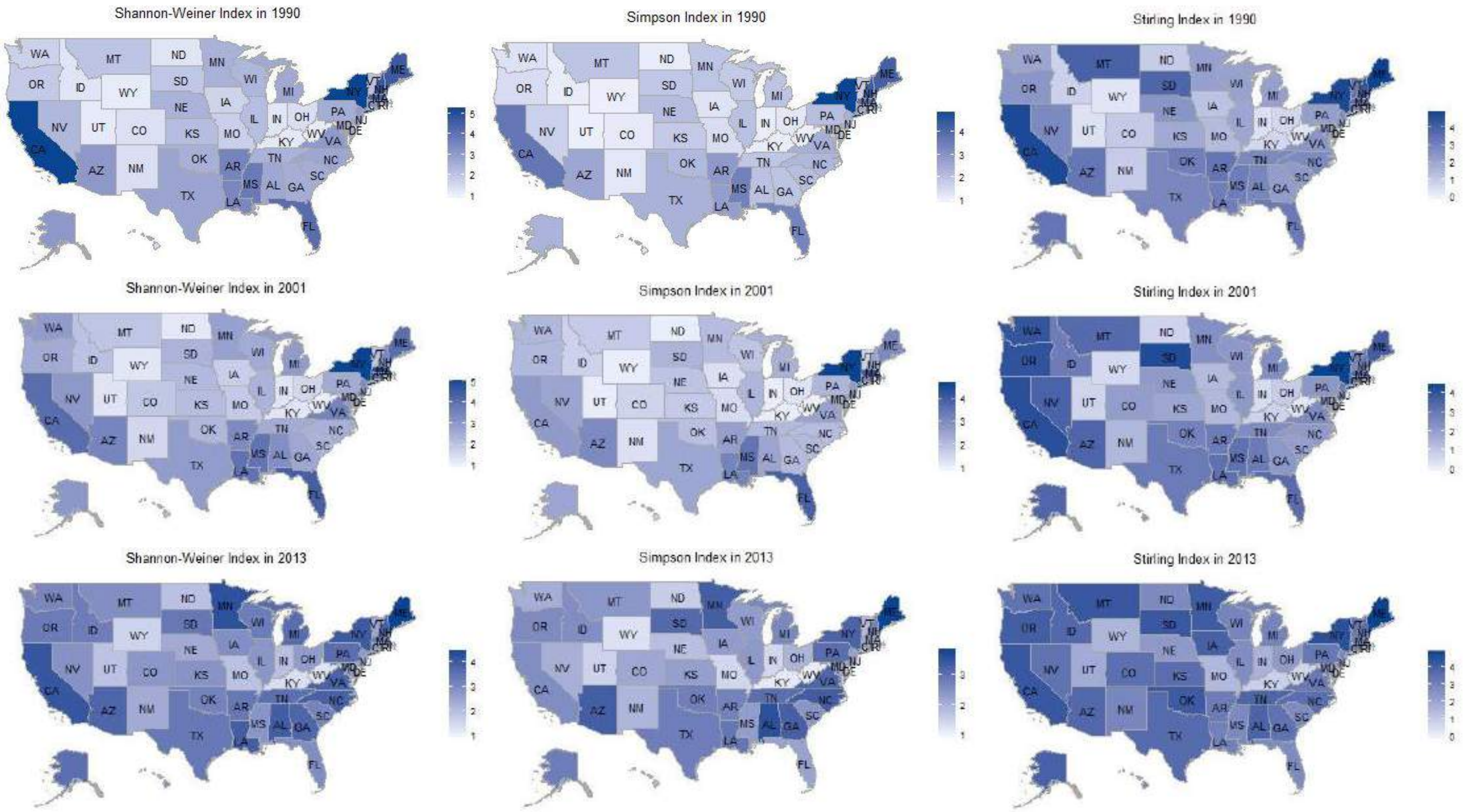
California, New York, Maine, and a few other Northeastern states appear to be the most diverse in 1990 for all three indices, indicating variety, balance, and disparity of PESs for these states. However, Montana and South Dakota appear to be noticeably more diverse in the Stirling Index compared to the Shannon-Wiener Index and Simpson Index. This is because the Stirling Index considers disparity in addition to variety and balance, and Montana and South Dakota both rely heavily on hydro and coal to generate the majority of their electricity (Figure 6, bottom figures).

Montana and South Dakota, which are dominated by two energy sources, do not exemplify what is traditionally considered diverse. This reflects the fact that disparity is typically ignored in diversity definitions. The inclusion of the disparity term in the Stirling Index results in noticeably different conclusions about which states are the most diverse.

As time progresses, more states become more

FIGURE 5

State-wise Shannon-Wiener, Simpson, and Stirling indices (left to right) in 1990, 2001, and 2013 (top to bottom). Darker shades represent greater diversity. The shading of the state maps indicates relative diversity compared to other states: the darker states are more diverse than the lighter states.



Shannon-Weiner Index in 1990

Simpson Index in 1990

Stirling Index in 1990

Shannon-Weiner Index in 2001

Simpson Index in 2001

Stirling Index in 2001

Shannon-Weiner Index in 2013

Simpson Index in 2013

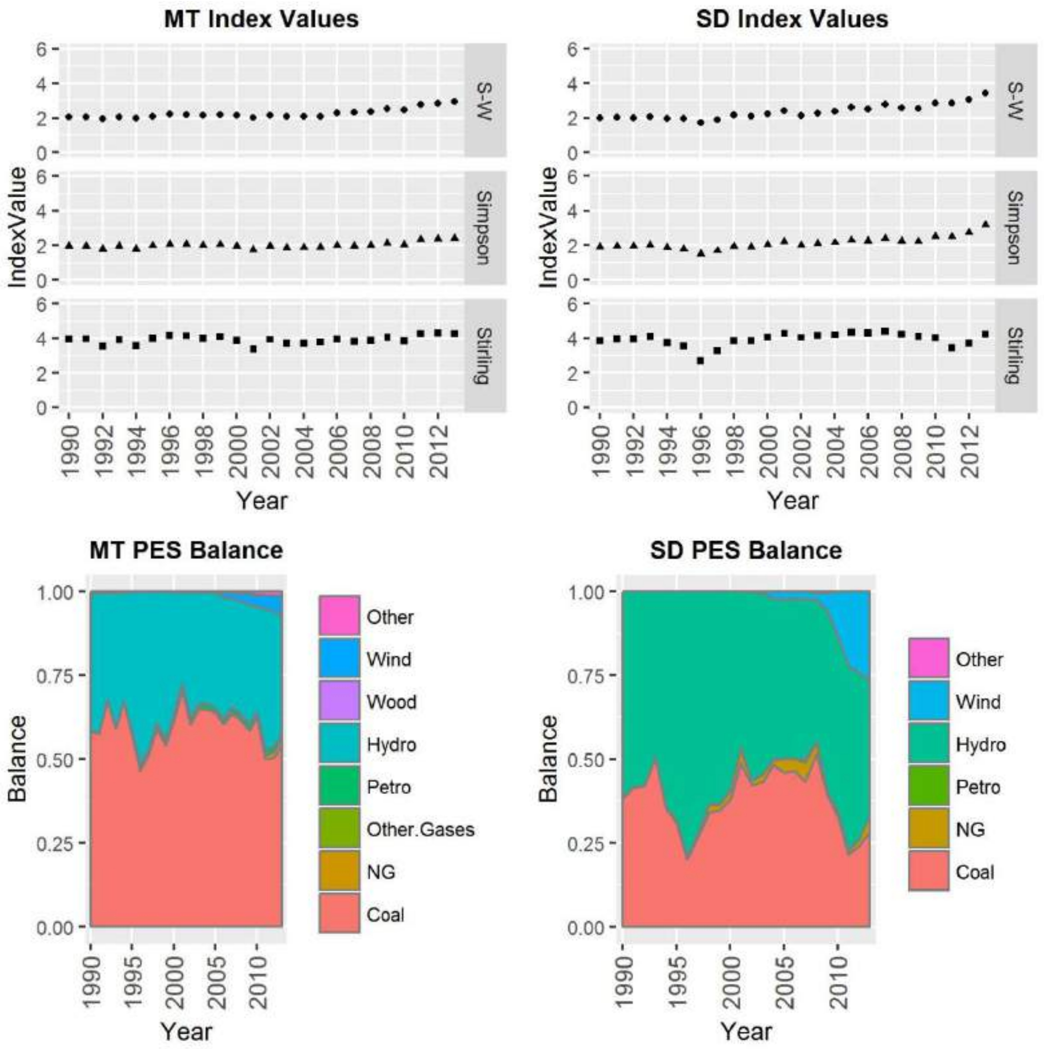
Stirling Index in 2013

diverse, as depicted by the relative darkening of the entire map. However, a few states noticeably lag behind in diversity. By 2013, Wyoming, Kentucky, and West Virginia appear white in the Shannon-Wiener Index map compared to the other states. In the Simpson Index map, Utah, Wyoming, Missouri, Indiana, Kentucky and West Virginia appear white compared to the other states. In the Stirling Index, Kentucky and West Virginia appear to be lagging the most in diversity. These states have continued to rely on very few PESs to generate their electricity.

Looking more closely at the actual rankings, we can further see which states remained consistent across the different indices and which states changed drastically. Table 1 shows the top ten states based

FIGURE 6:

Diversity and balance trends for Montana and South Dakota. The top two figures show the Shannon-Wiener, Simpson, and Stirling index values (top to bottom) from 1990 to 2013. The bottom two figures show the balance of PESs used to generate electricity in the states from 1990 to 2013.



on the Shannon-Wiener Index, Simpson Index, and Stirling Index for the years 1990, 2001, and 2013 (see *Supplemental Information* for ranking for each U.S. state).

New York (1990, 2001, 2013; 1990, 2001, 2013; 1990, 2001, 2013)[2], California (90, 01, 13; 90; 09, 01, 13), New Hampshire (90; 90; 90), Maine (90, 01, 13; 90, 01, 13; 09, 01, 13), Massachusetts (90, 01; 90, 01; 90, 01), Arkansas (90; 90; 90), and Minnesota (13; 13; 13) appear in the top ten most diverse states for all three indices during at least one of the three years. New York (Figure 3, left side figures) and Maine remain in the top ten list for all three years and for all three indices. This suggests that these two states consistently exhibit high levels of variety, balance, and disparity as it pertains to PESs used to generate electricity. Minnesota (Figure 4, left side) appears in the top ten list for all three indices in 2013 but not in the previous years. As previously described, Minnesota's increase in diversity is primarily due to its increased use of wind energy. California

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[2] The notation $S(x_i;y_j;z_k)$ means that state S was in the top ten states with highest: Shannon-Wiener index in year x_i, Simpson index in years y_j, and Stirling index in years z_k.

TABLE 2:

Top ten diverse states based on the Shannon-Wiener Index, Simpson Index, and Stirling Index for the years 1990, 2001, and 2013. "US" corresponds to the entire U.S. as the unit for calculating the indices.

	Shannon-Wiener Index			Simpson Index			Stirling Index		
Rank	**1990**	**2001**	**2013**	**1990**	**2001**	**2013**	**1990**	**2001**	**2013**
1	NY	NY	US	NY	NY	ME	ME	NY	ME
2	CA	MA	ME	NH	MA	US	CA	SD	NY
3	NH	FL	MN	ME	FL	AL	NY	CA	MT
4	ME	CT	CA	MA	MS	NC	NH	OR	CA
5	MA	CA	NY	CA	LA	MN	MT	WA	SD
6	FL	ME	AL	MS	CT	AZ	SD	ME	OK
7	US	US	LA	FL	ME	GA	US	NV	MN
8	MS	LA	NC	US	AZ	NY	MA	AZ	US
9	AR	MS	NH	AR	US	VA	AK	AK	OR
10	LA	VA	VA	LA	DE	SD	AR	MA	IA

remains in the top ten list for all three years for the Shannon-Wiener Index and the Stirling Index but only appears in the Simpson Index in 1990. This suggests that California was relatively less balanced during 2001 and 2013 even though it generated electricity from a large number of disparate PESs.

From Figure 7, we can see that California's generation portfolio has relied increasingly more on natural gas through the years. This has led to a downward trend in diversity for all three indices. In 2001 and 2013, California's index values were significantly lower for all three indices. During 2001 and 2013, California used proportionally more natural gas compared to other years and reduced the proportion of electricity generated from hydro. This change made California's generation portfolio less balanced dropping its Simpson Index rank to 11th and 22nd for the years of 2001 and 2013, respectively.

FIGURE 7

Diversity index and balance trends for California. The left figure shows the Shannon-Wiener, Simpson, and Stirling index values (top to bottom) from 1990 to 2013. The right figure shows the balance of PESs used to generate electricity in the states from 1990 to 2013.

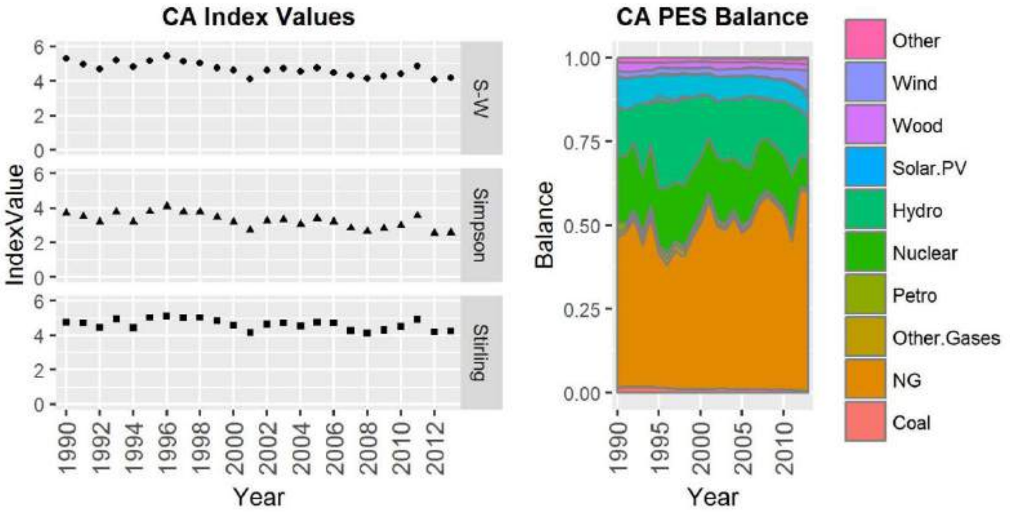
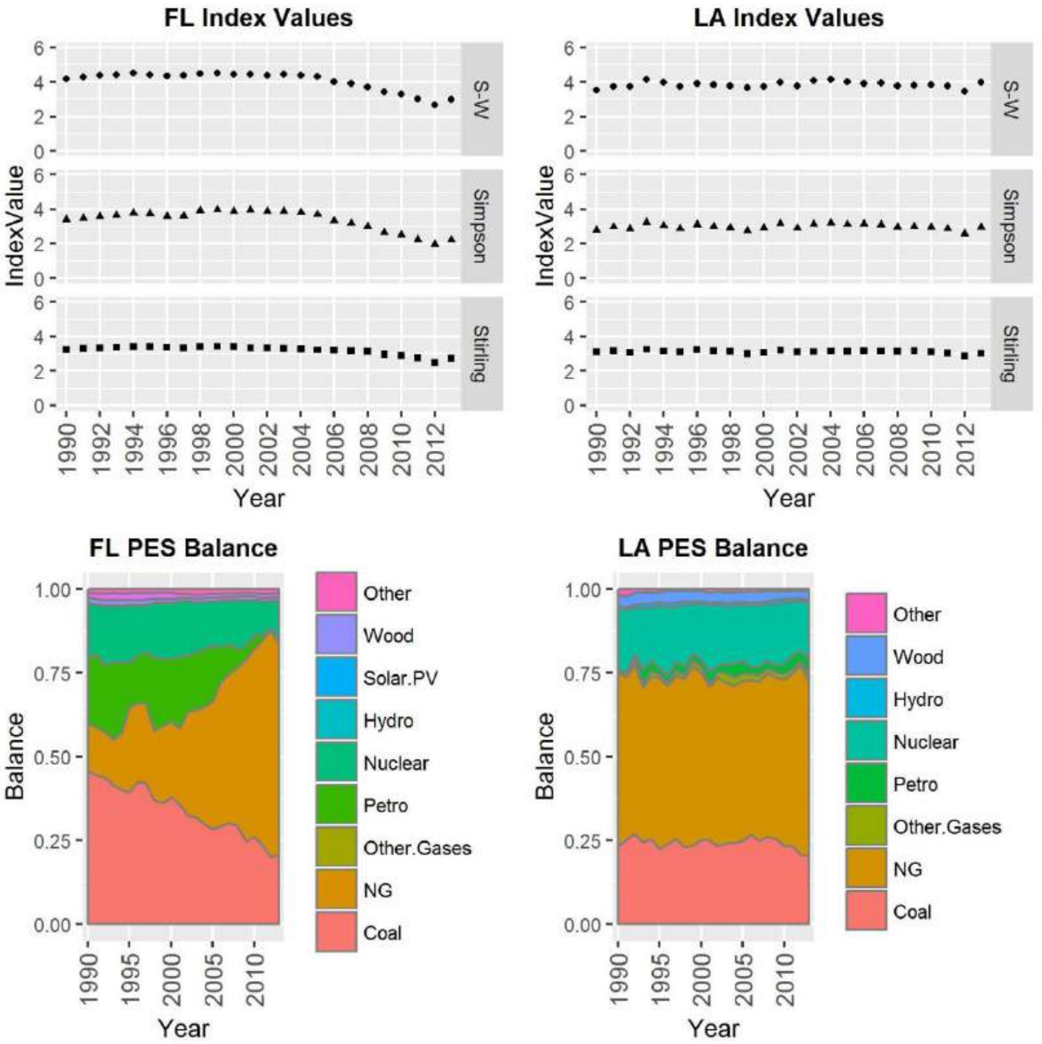


FIGURE 8

Diversity index and balance trends for Florida and Louisiana. The top two figures show the Shannon-Wiener, Simpson, and Stirling index values (top to bottom) from 1990 to 2013. The bottom two figures show the balance of PESs used to generate electricity in the states from 1990 to 2013.



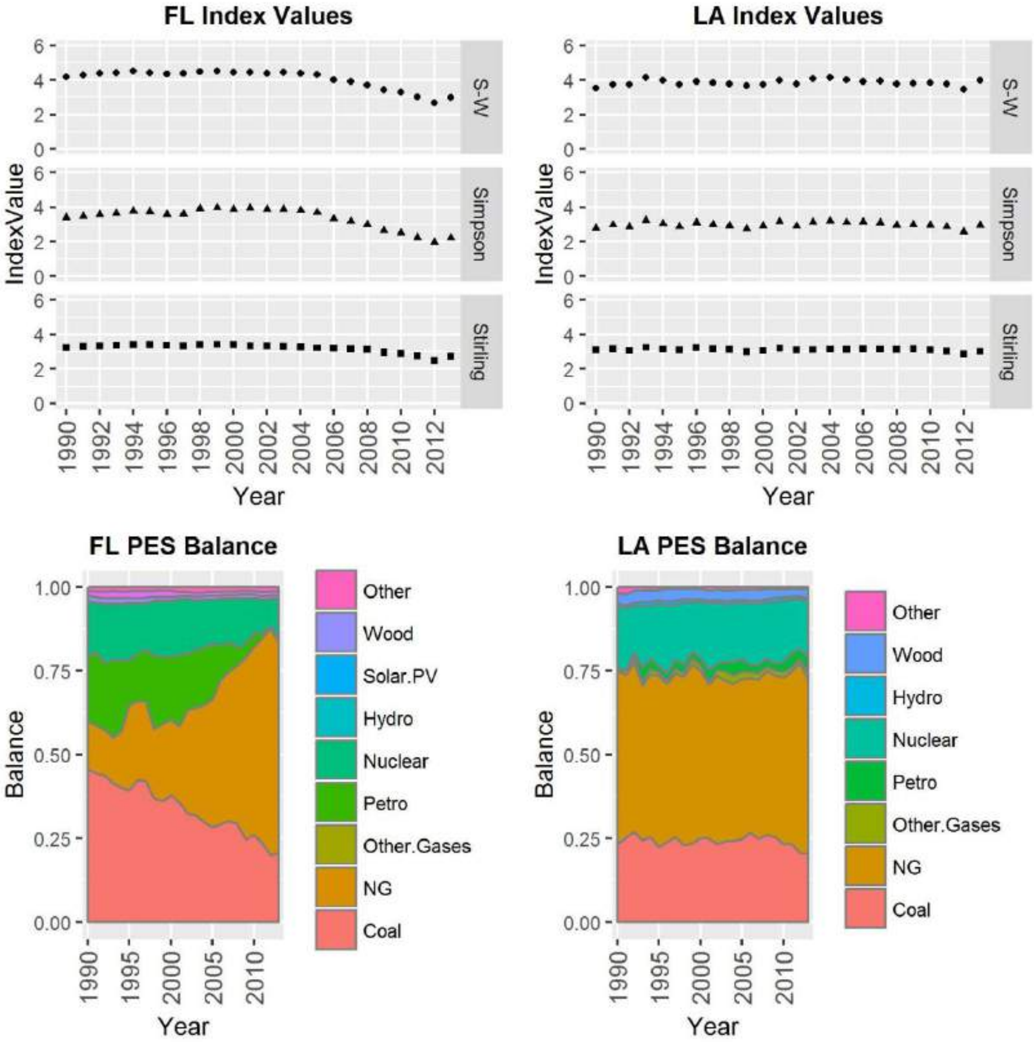
Florida (90, 01; 90, 01; NA), Mississippi (90, 01; 90, 01; NA), Louisiana (90, 01, 13; 90, 01; NA), Connecticut (01; 01; NA), Virginia (01, 13; 13; NA), Alabama (13; 13; NA), and North Carolina (13; 13; NA) show up in the top ten of the Shannon-Wiener Index and Simpson Index but not in the Stirling Index. We can expect that the states that show up in these two indices and not in the Stirling Index have large numbers of different PESs that are not as disparate.

Florida and Louisiana are great examples of how states can have high variety and balance but low disparity. Both states have relied more heavily on coal, petroleum, natural gas, and nuclear than on renewable resources such as hydro and wind. While both states have, at times, been well balanced across a number of different PESs, the PESs that they do use to generate electricity are relatively similar (refer to Figure 1). It should also be noted that Florida's diversity index value has been negatively affected by its increased reliance on natural gas, similar to New York and Massachusetts (Figure 3).

Alabama and North Carolina rose to the top ten list in 2013 for the Simpson Index and Stirling Index. These two states benefited from the adoption of more natural gas at the expense of some coal

FIGURE 9

Diversity index and balance trends for Alabama and North Carolina. The top two figures show the Shannon-Wiener, Simpson, and Stirling index values (top to bottom) from 1990 to 2013. The bottom two figures show the balance of PESs used to generate electricity in the states from 1990 to 2013.



(Figure 9, bottom figures). Coal was not completely eliminated from the generation portfolio, thus Alabama and North Carolina became more balanced across more PESs.

Arizona (NA; 01, 13; 01) and South Dakota (NA; 90; 90, 01, 13) appear in the top ten most diverse states according to the Simpson Index and Stirling Index. These states score high in balance and disparity during the years they are ranked in the top ten list. As described earlier, South Dakota (Figure 6, right side figures) has a relatively low number of PESs that it uses to generate electricity. Despite the low number, South Dakota's generation portfolio is well balanced and disparate. Because of the high disparity of coal and hydro, South Dakota remains in the top list for all three years evaluated. Although Arizona only shows up a few times in the top ten lists, its rank never dropped below 14 for any of the diversity indices. It has remained relatively diverse.

Georgia (NA; 13; NA) and Delaware (NA; 01; NA) are the only states that only show up in the top ten list for the Simpson Index. This indicates that they score high in balance and not in variety and disparity. Similar to Alabama and North Carolina, Georgia's diversity index values were positively

TABLE 3

Bottom Ten States Based on the Shannon-Wiener Index, Simpson Index, and Stirling Index for the Years 1990, 2001, and 2013.

	Shannon-Wiener Index			Simpson Index			Stirling Index		
Rank	**1990**	**2001**	**2013**	**1990**	**2001**	**2013**	**1990**	**2001**	**2013**
43	OH	NM	DE	OH	IA	DE	NM	IA	OH
44	CO	OH	ND	CO	OH	ND	ND	OH	UT
45	ID	UT	IN	ND	UT	UT	ID	KY	DE
46	ND	IN	MO	ID	IN	MO	OH	ND	IN
47	IN	KY	UT	KY	KY	IN	KY	UT	WY
48	KY	WY	WY	IN	ND	WY	IN	WY	MO
49	UT	ND	KY	UT	WY	KY	UT	IN	KY
50	WY	RI	WV	WY	RI	WV	WY	WV	WV
51	WV	WV	RI	WV	WV	RI	WV	RI	RI
52	DC	DC	DC	DC	DC	DC	DC	DC	DC

influenced by the increased use of natural gas to generate electricity. Georgia's balance across PESs improved as a result. Similar to New York, Massachusetts, and Florida, Delaware's diversity index values were negatively influenced by the drastic increase in natural gas use following 2010. Between 1994 and 2005, Delaware was well balanced across coal, natural gas, and petroleum which raised its Stirling Index rank in 2001. Compared to other states, however, Delaware did not have many PESs, and the PESs it did use to generate electricity were not disparate.

Montana (NA; NA; 90, 13), Alaska (NA; NA; 90, 01), Washington (NA; NA; 01), and Oregon (NA; NA; 01, 13) rank in the top ten list for the Stirling Index only. Of note, the Stirling Index list has the most number of states that only show up in its top ten list versus the number of states that only show up in the other two top ten lists. These states generally have a small number of different PESs that are not well balanced across those PESs, but are highly disparate PESs. Montana (Figure 6, left side figures) is a great example of this. Approximately 60% of Montana's power is generated by coal, with the remainder generated by hydro. The proportionate electricity generated from coal and hydro is well-balanced, which gives Montana a relatively high Stirling Index (approximately 4.2), given the very disparate nature of coal and hydro generation (see Figure 1). However, it does not use many other types of PESs in significant quantities, so its Simpson and Shannon-Wiener Indices values are relatively lower.

As shown in Table 3 the bottom ten states for all three indices for the years 1990, 2001, and 2013 are relatively more consistent over time. In some cases, such as D.C. and Rhode Island, states rank low because they are small and do not generate as much electricity. In other cases, the state relies almost exclusively on coal or natural gas as a result of resource availability. Thus the low ranked states are generally highly dominated by one resource. As a result of heavy reliance on one energy source, these states have very poor variety, balance, and disparity.

DIVERSITY TRENDS IN REGIONAL ENTITIES

With the exception of NPCC, all of the regional entities have been increasing in diversity for all three indices (see *Supplemental Information* for similar charts for each of the six regional entities considered in this paper). Similar to trends seen in individual states, most of the changes are a result of natural gas and wind adoption.

FIGURE 10

NPCC diversity indices and PES balance from 1990 to 2013. The left figure shows the Shannon-Wiener, Simpson, and Stirling index values (top to bottom) from 1990 to 2013. The right figure shows the balance of PESs used to generate electricity in the states from 1990 to 2013.

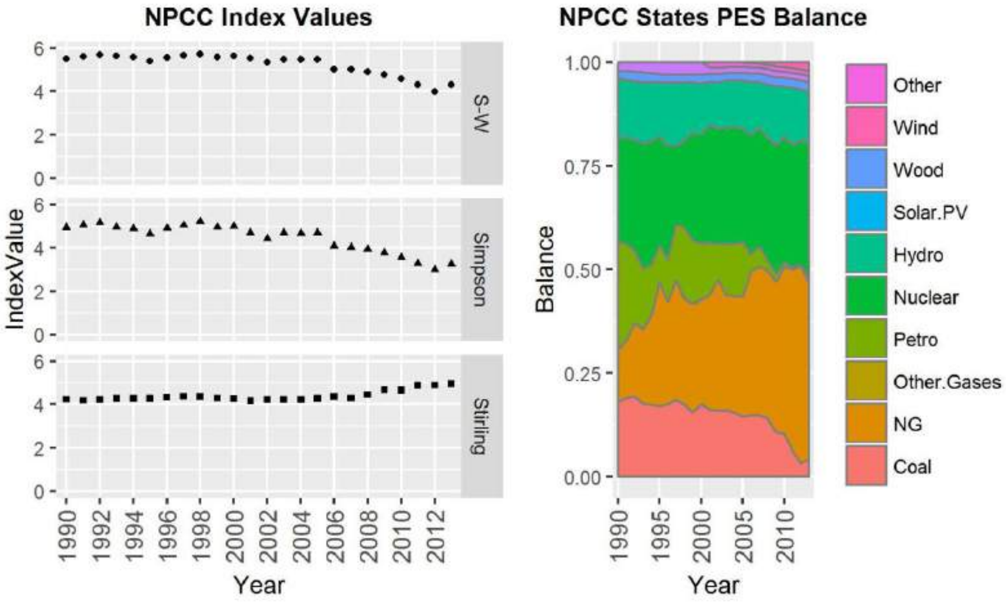
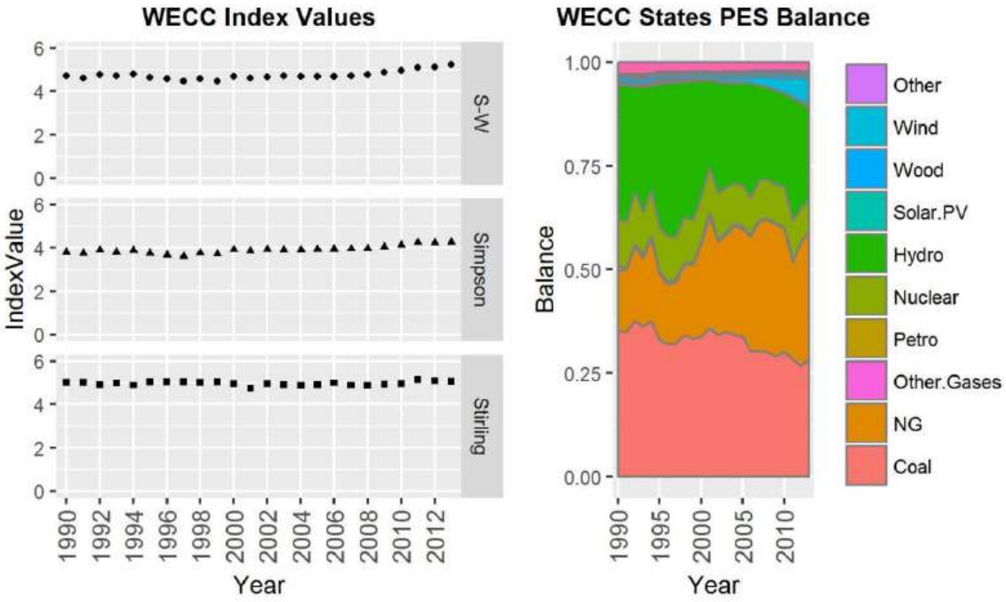


FIGURE 11

WECC diversity indices and PES balance from 1990 to 2013. The left figure shows the Shannon-Wiener, Simpson, and Stirling index values (top to bottom) from 1990 to 2013. The right figure shows the balance of PESs used to generate electricity in the states from 1990 to 2013.



NPCC had the highest diversity index values compared to the other regional entities. Many of the states within NPCC are also included in the top ten lists previously mentioned. These states include Connecticut, Massachusetts, Maine, New Hampshire, and New York. NPCC's trend almost mimics that of New York and Massachusetts. Starting in 2005, NPCC began increasing the proportion of electricity generated from natural gas while almost completely eliminating the proportion of electricity generated from coal and petroleum. As a result, the Shannon-Weiner and Simpson index values decreased. In contrast, the Stirling Index remained relatively constant until around 2007 where an obvious upward trend can be seen. The Stirling Index was mostly unaffected by the transition from coal and petroleum to natural gas since those PESs are relatively similar (See Figure 1). However, small changes to the amount of wind that was adopted in NPCC caused the Stirling Index to markedly change. The proportion of electricity generated by wind from 2006 to 2013 increased from 0.2% to 2.2% in the NPCC states.

WECC has relatively high diversity values similar to NPCC. This is to be expected considering many of its states are also in the top ten lists. These states include Arizona, California, Montana, Oregon, and Washington. While WECC also increased the amount of electricity generated from natural gas, it still maintained a relatively high percentage of generation from coal and natural gas as can be seen from Figure 11. This helped it maintain high diversity index values as compared to NPCC. In 2004, WECC started generating more electricity from wind, increasing the percentage of wind generated electricity from 1% to 6%.

SERC and RFC have both seen an increase in diversity from the transition from coal to natural gas. SERC has the next highest diversity scores compared to the other regional entities while RFC ranks the lowest among the regional entities. Since a large amount of electricity continues to be generated by coal in both regional entities, SERC and RFC could continue to benefit (in terms of diversity) from adopting more natural gas.

SPPRE and MRO have both increased the proportion of electricity generated from wind and natural gas leading to increased diversity on all three indices. Continued adoption of these resources will displace more coal and positively impact the regions’ diversity. ■

CONCLUSION

Diversity of primary energy sources used to generate electricity has increased for the U.S. as a whole as each state adopts new types of energy sources, in particular natural gas and wind. If a state traditionally generated the majority of its electricity from conventional, thermal resources, adoption of wind increased the diversity of the state. If a state did not traditionally use much natural gas to generate electricity, adoption of natural gas increased its diversity some. In states and regions that historically generated electricity from a large number of PESs and had very high diversity index values, diversity had a tendency to trend downward. This is in large part a result of transitioning away from coal and petroleum to cleaner PESs such as natural gas. For these states to maintain or increase the diversity of the electricity system as it relates to PESs, they will need to use more renewable sources such as wind, solar, hydro, geothermal, or municipal/industrial waste and balance it against higher uses of natural gas. Of course, this point sees the generation portfolio through the singular lens of diversity, while the full range of drivers impacting a state's generation portfolio are much more complicated.

The Shannon-Wiener Index, Simpson Index, and Stirling Index do not necessarily follow the same trends within a state or region. States rank higher on the Shannon-Wiener Index and Simpson Index if they have a large variety of PESs and are well-balanced across PESs. Even as similar as the Shannon-Wiener Index and Simpson Index are, changes in balance can cause the relative ranking of states to change drastically between the two indices as was the case in California. The Stirling Index ranked the states much differently than the Shannon-Wiener Index and Simpson Index. It places more emphasis on disparity, so even if a state has very few PESs, the state can still rank relative high on the Stirling Index if the PESs are very disparate. Such was the case for Minnesota. In some cases such as for NPCC, the Stirling Index trended in the opposite direction as the Shannon-Wiener Index and Simpson Index. The addition of the disparity term noticeably altered the relative diversity rankings and trends of each of the states and regional entities.

The increased use of natural gas in the U.S. in recent years has caused the Shannon-Wiener Index and Simpson Index to shift in either direction depending on the degree to which it replaces an incumbent PES such as coal or petroleum. If natural gas almost completely displaced coal and/or petroleum, the Shannon-Wiener Index and Simpson Index trended downward, such was the case for New York, Massachusetts, Florida, and NPCC. If the overall proportion of electricity generated from natural gas, coal, and petroleum remained relatively stable, however, the Stirling Index was not as adversely affected as the other two indices. If natural gas only partially displaced coal and petroleum, states and regional entities generally benefited in diversity. Such was the case for Alabama, North Carolina, and many of the regional entities.

The two major drivers in this study, natural gas and wind, show that there is more than one way for diversity to change. In the case of natural gas, low prices were the main driver. In the case of wind, federal and state policies were the main driver, especially early on, that incentivized more wind generation. In general, if states want to continue increasing the diversity of their electricity system, they will need to adopt generation sources that are different from what they already have. This may mean choosing less economic or environmental options with the possible benefit of increasing their diversity, and potentially resilience.

As noted before, this article focused to analyzing the electricity market based on PESs and data readily available from the U.S. EIA. Future studies can go beyond what has been done here to look at diversity in other parts of the electricity sector such as location, size (i.e., capacity of the generation units), different generation technologies, different retail technologies, etc. This study also assumed disparity measures would be the same as one of the experts from the Yoshizawa *et al.* 2009 study. These disparity measures could be calculated based on experts in the U.S. for a more accurate, local view. Additional research can also be done to evaluate the specific policies that states are implementing that affect the diversity of their electricity system.

While decision makers should not solely rely on diversity of energy sources when making infrastructure and policy decisions related to electricity supply, they should at least consider how emphasizing on the economics, reliability, and environmental implications of various electricity supply options impact the diversity of the electricity system. In many cases, diversity could be in direct opposition to these other priorities. By considering diversity as a criterion, this inherently means one may not always choose the cheapest electricity generation option. Diversity could also mean not choosing the most environmentally benign option and keeping some traditional resources such as coal and natural gas for the sake of higher diversity. With these dynamics in mind, in this paper we have empirically demonstrated some of the key tradeoffs that need to be considered when considering diversity as a decision preference. ■

ACKNOWLEDGEMENTS

Feedback on earlier versions of this paper from Ariane Beck, Carey King, D. Cale Reeves, and Jay Zarnikau is gratefully acknowledged. VR acknowledges funding from the UT Austin Energy Institute. All remaining errors are ours alone.

SUPPLEMENTAL INFORMATION

The *Supplemental Information* for this paper contains three sets of additional results complementary to the data and results presented in the main text of this paper: (i) Electricity generation diversity and balance for each U.S. state between 1990-2013, (ii) Electricity generation diversity and balance for each U.S. region and U.S. overall between 1990-2013, and (iii) Diversity ranking for all states and U.S. overall in 1990, 2001, and 2013.

1. DIVERSITY AND BALANCE TRENDS FOR EACH STATE

FIGURE SI-1

Diversity and balance trends for Alaska.

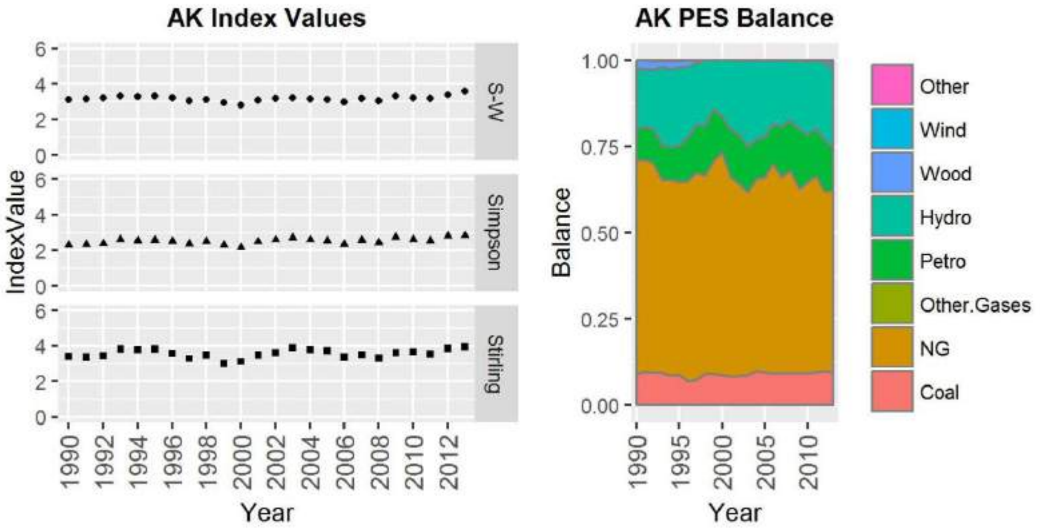


FIGURE SI-2

Diversity and balance trends for Alabama.

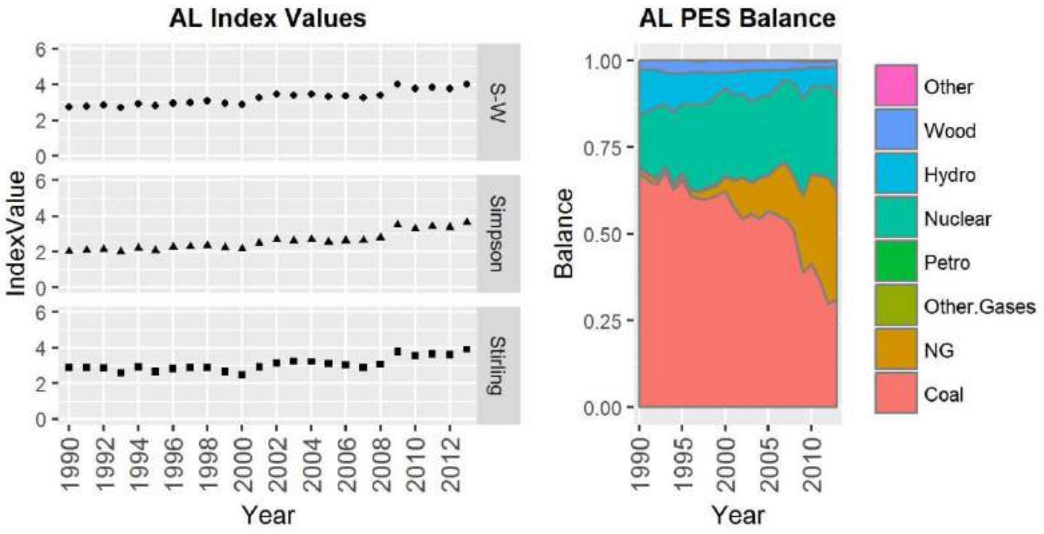


FIGURE SI-3

Diversity and balance trends for Arkansas.

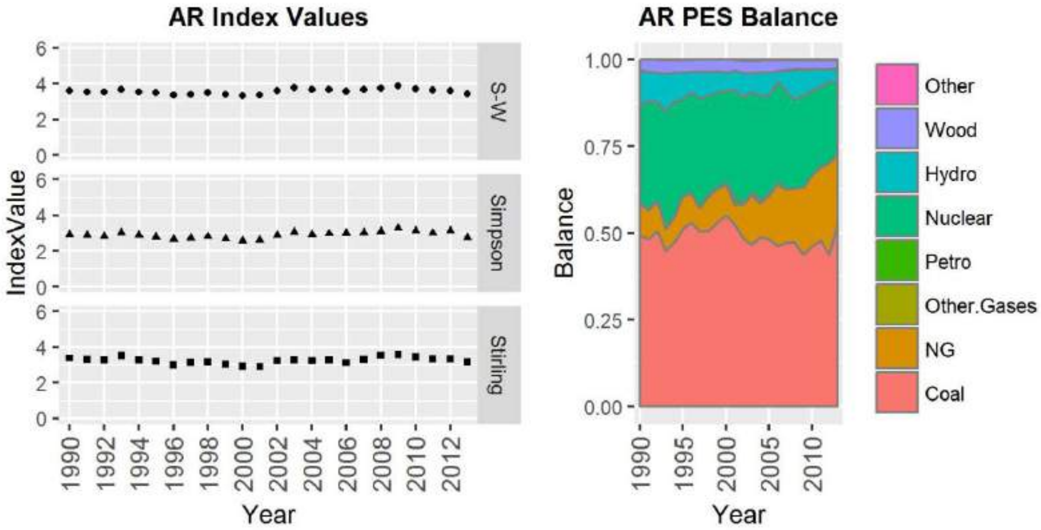


FIGURE SI-4

Diversity and balance trends for Arizona.

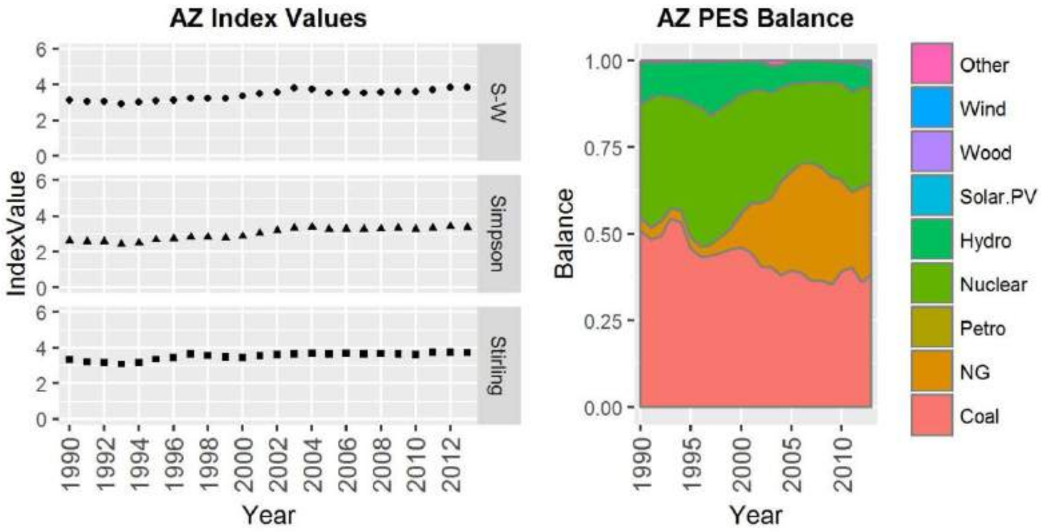


FIGURE SI-5

Diversity and balance trends for California.

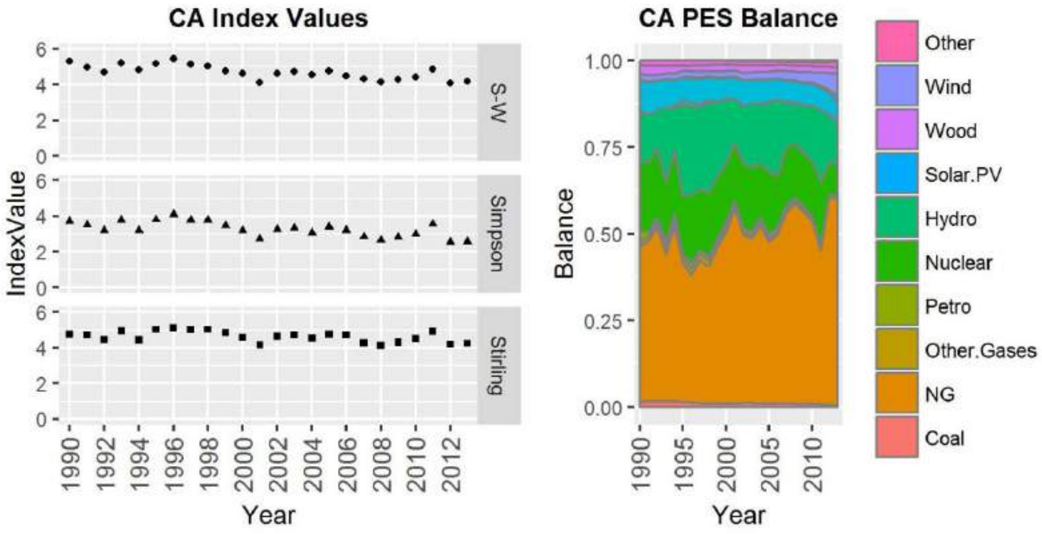


FIGURE SI-6

Diversity and balance trends for Colorado.

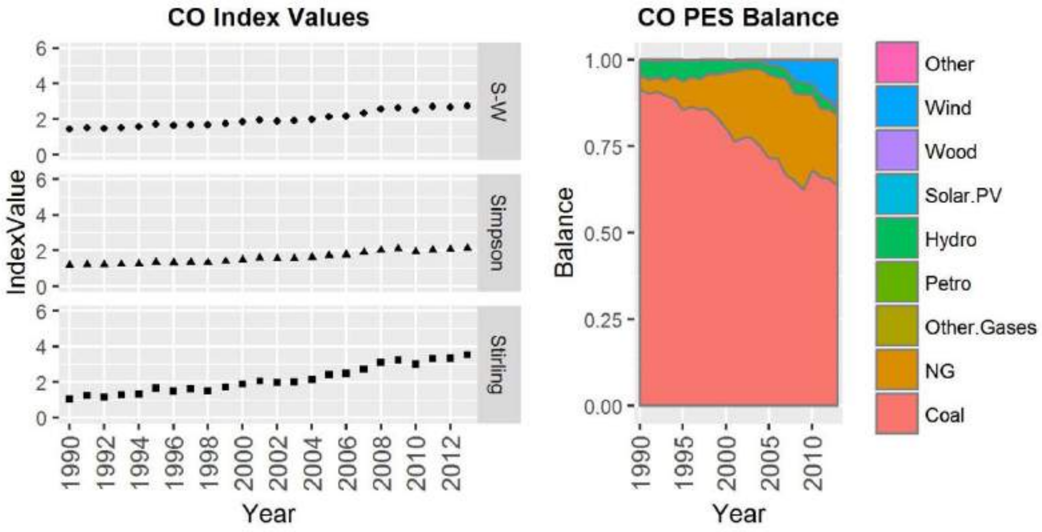


FIGURE SI-7

Diversity and balance trends for Connecticut.

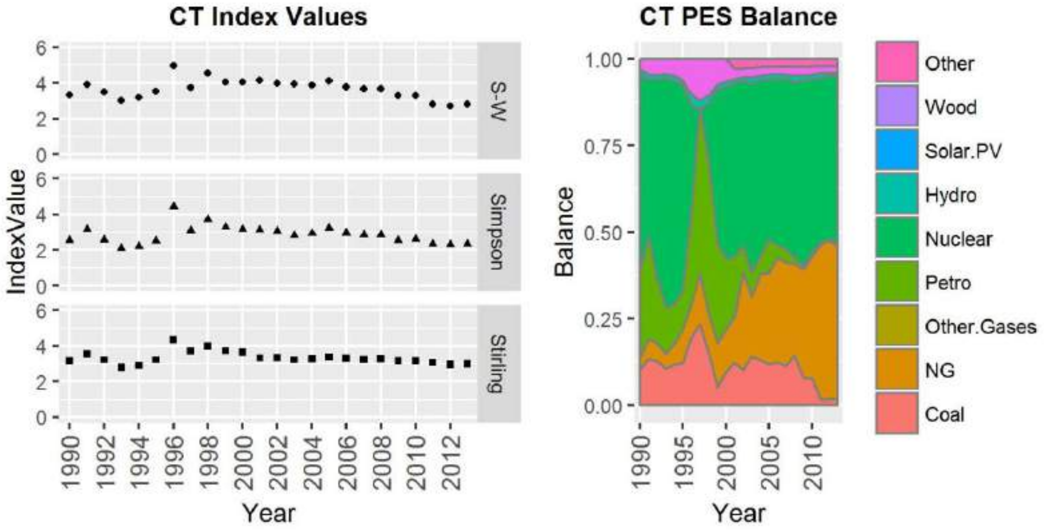


FIGURE SI-8

Diversity and balance trends for District of Columbia.

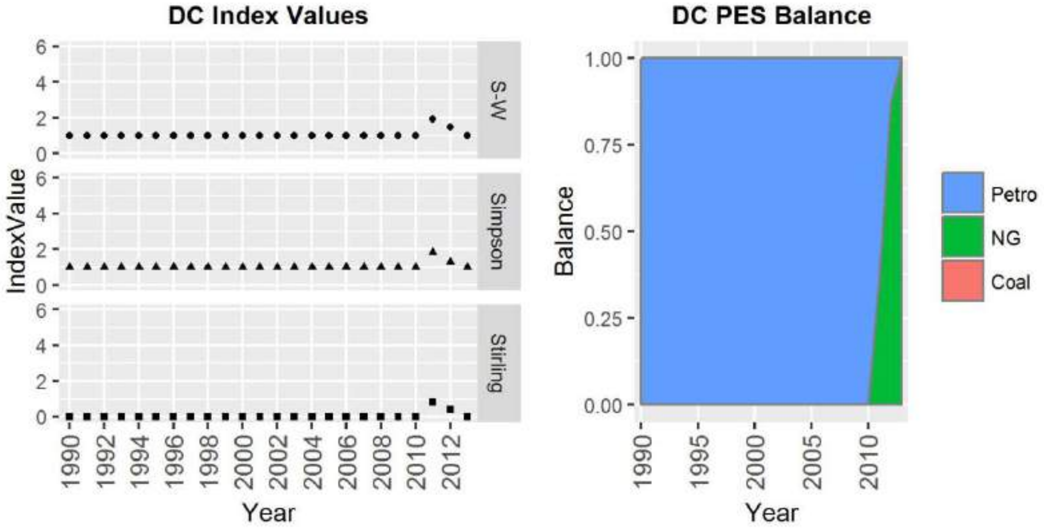


FIGURE SI-9

Diversity and balance trends for Delaware.

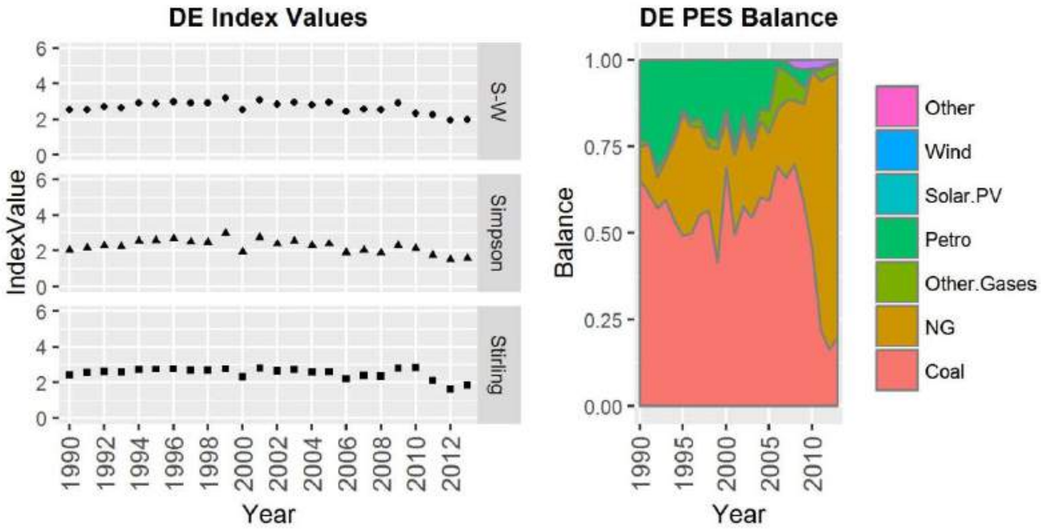


FIGURE SI-10

Diversity and balance trends for Florida.

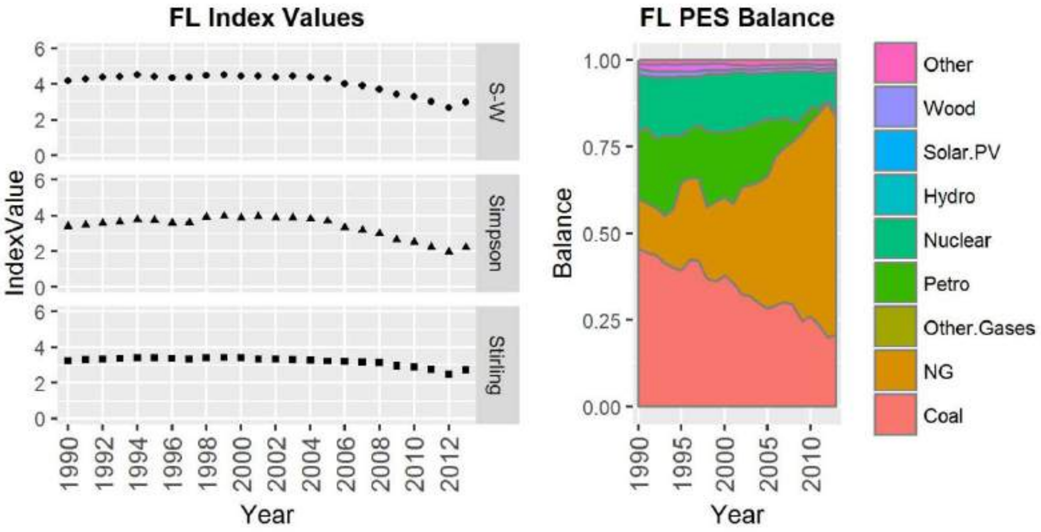


FIGURE SI-11

Diversity and balance trends for Georgia.

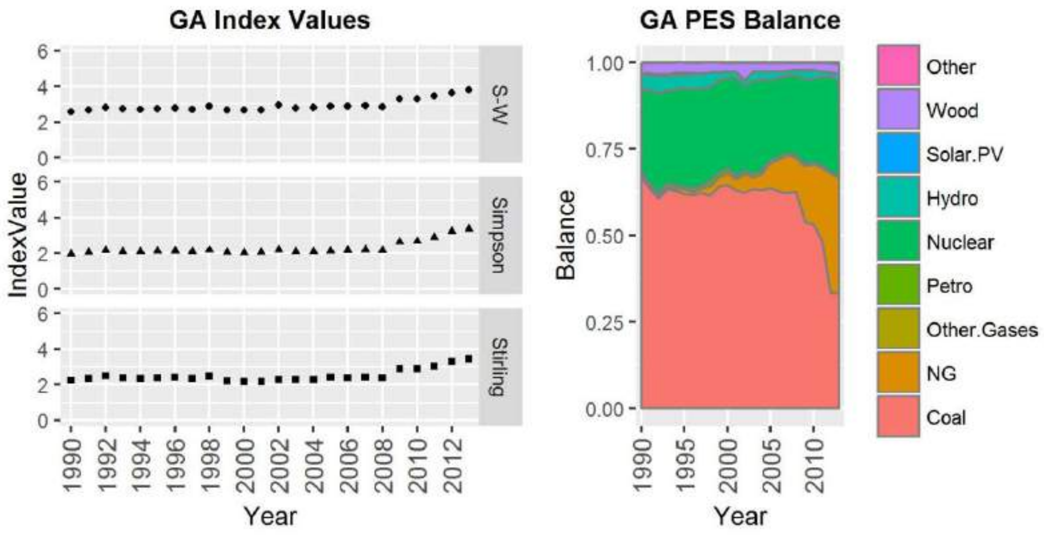


FIGURE SI-12

Diversity and balance trends for Hawaii.

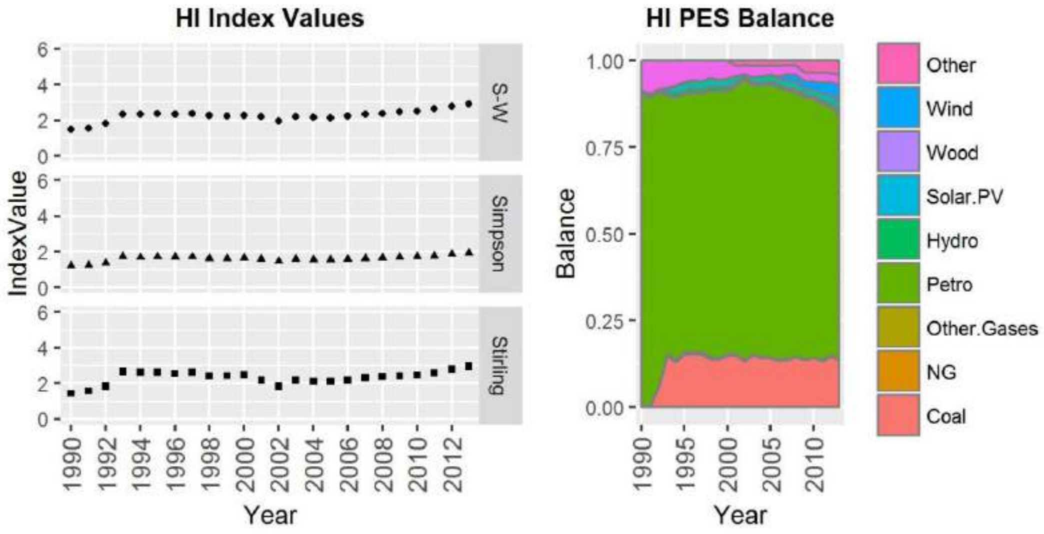


FIGURE SI-13

Diversity and balance trends for Iowa.

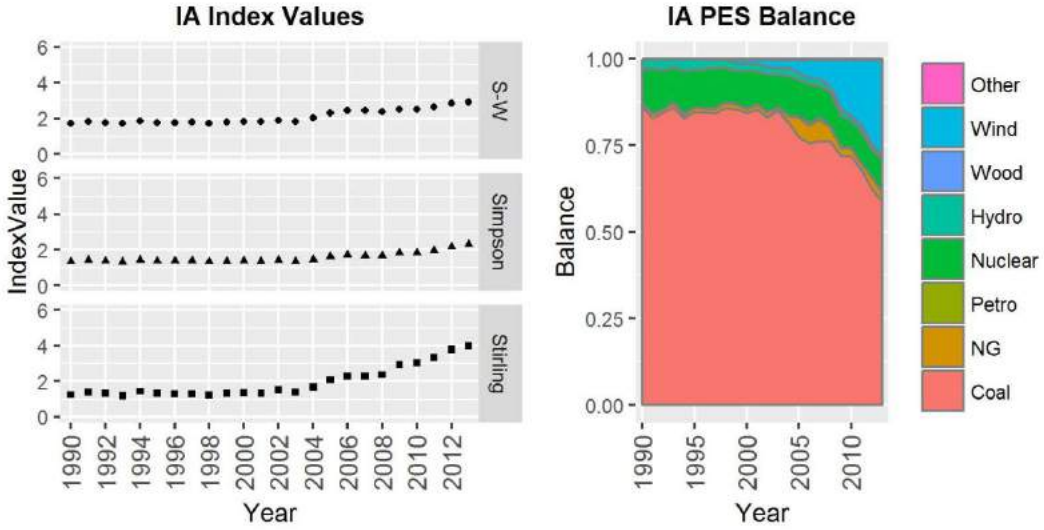


FIGURE SI-14

Diversity and balance trends for Idaho.

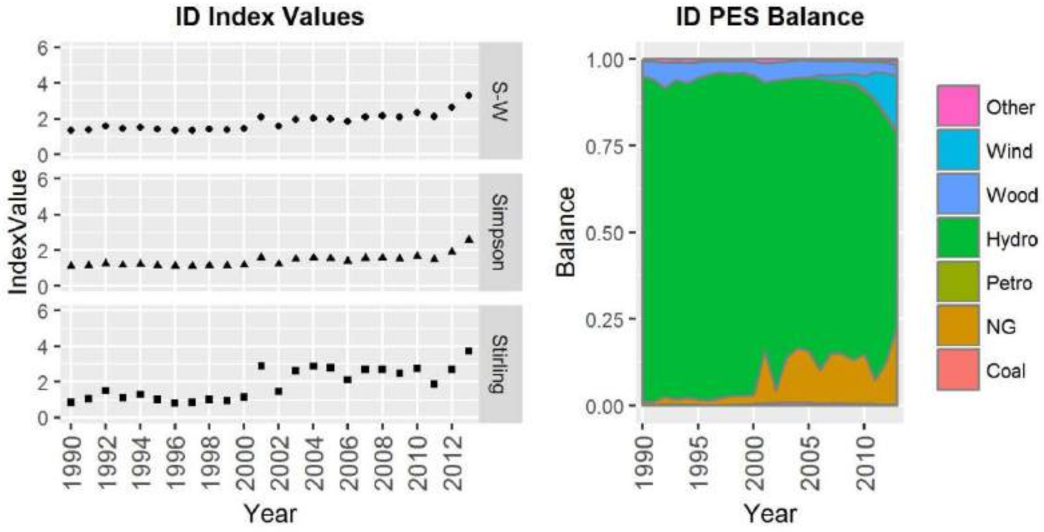


FIGURE SI-15

Diversity and balance trends for Illinois.

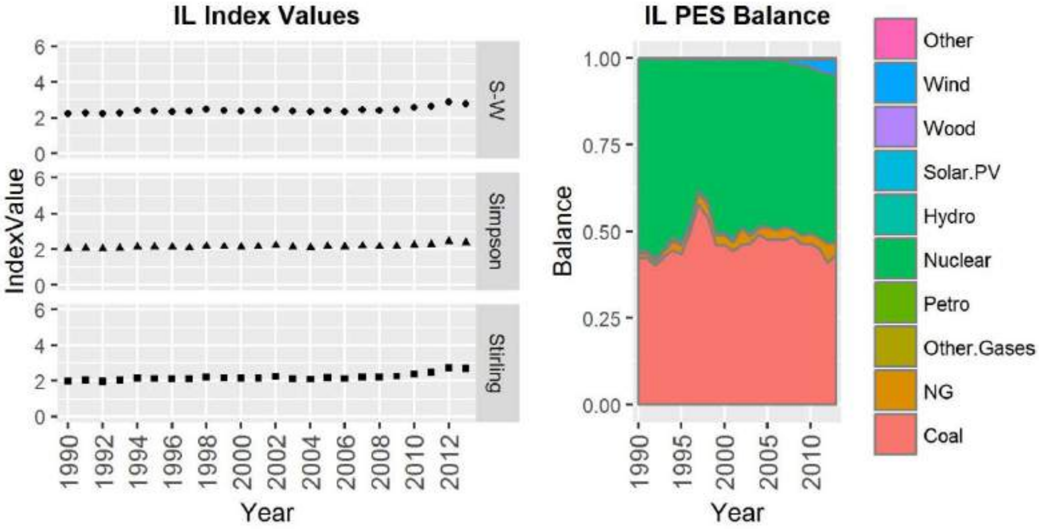


FIGURE SI-16

Diversity and balance trends for Indiana.

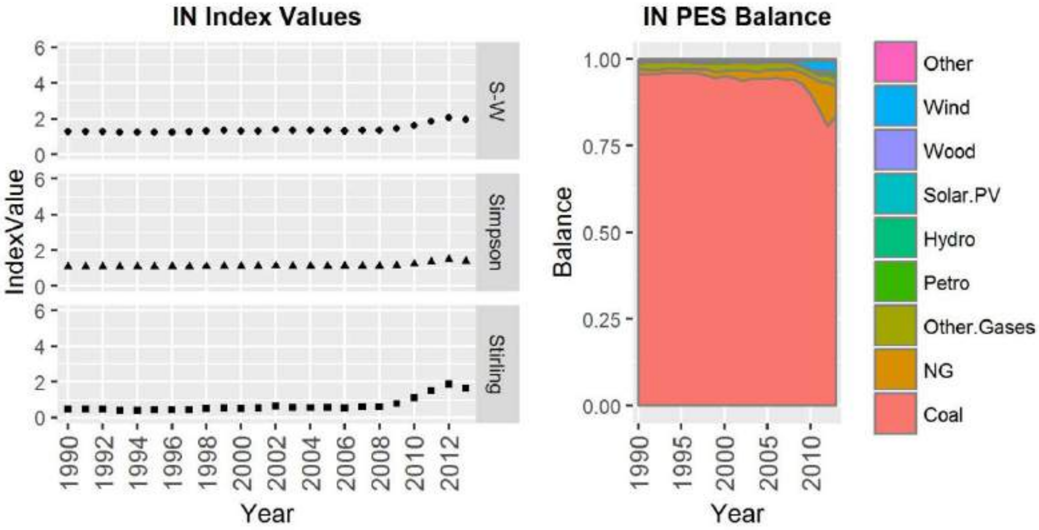


FIGURE SI-17

Diversity and balance trends for Kansas.

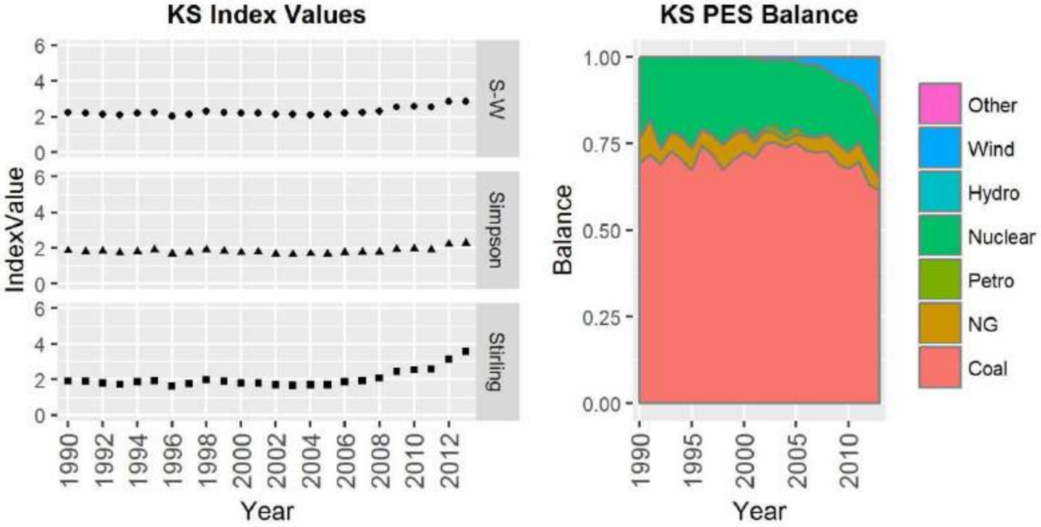


FIGURE SI-18

Diversity and balance trends for Kentucky.

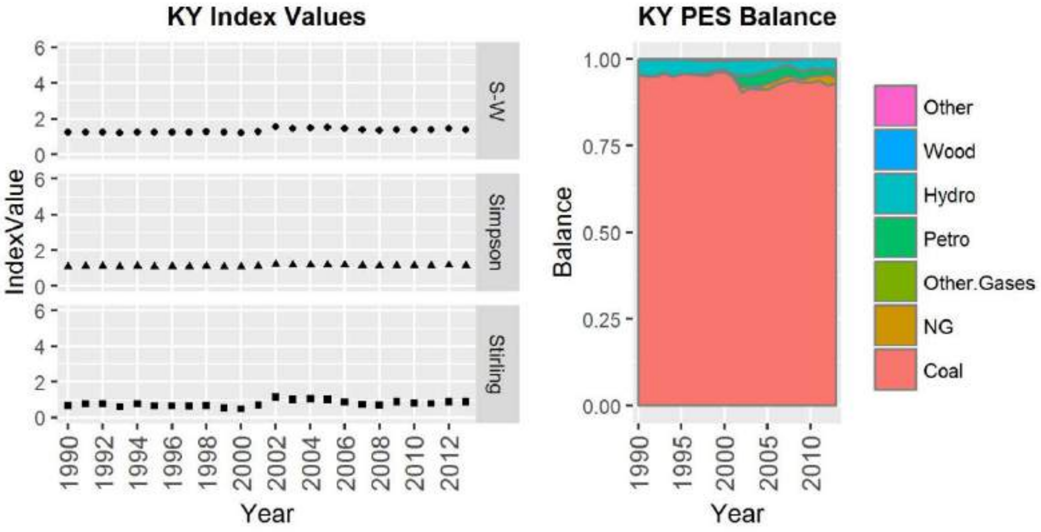


FIGURE SI-19

Diversity and balance trends for Louisiana.

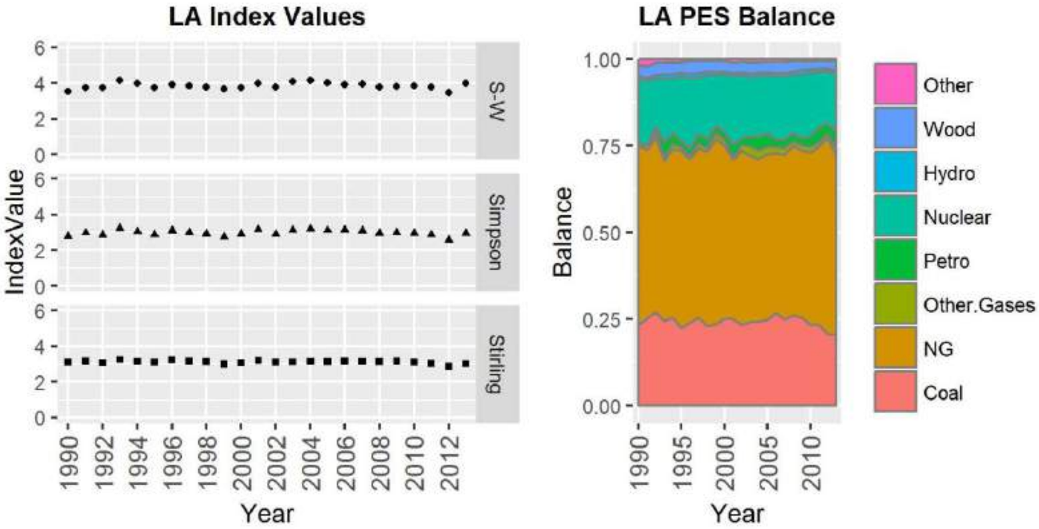


FIGURE SI-20

Diversity and balance trends for Massachusetts.

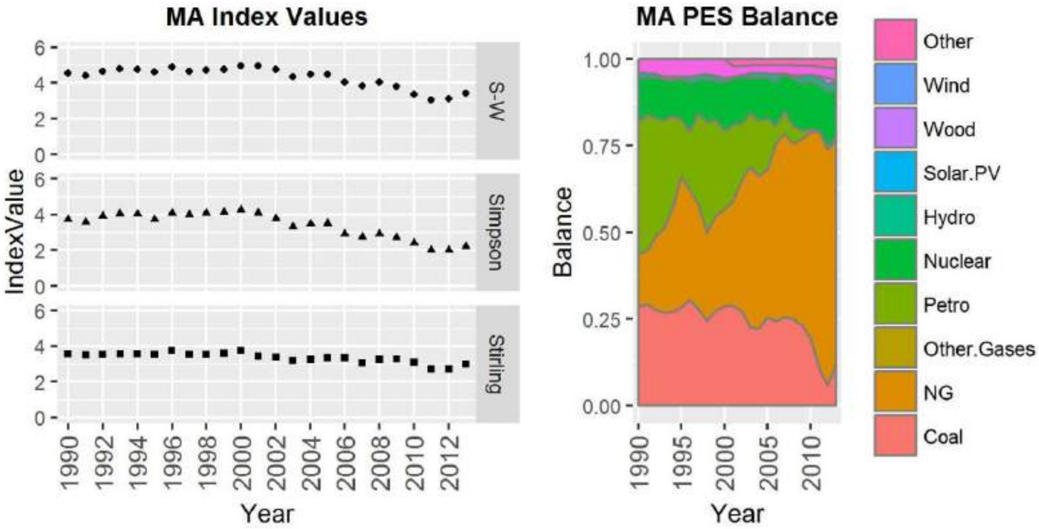


FIGURE SI-22

Diversity and balance trends for Maryland.

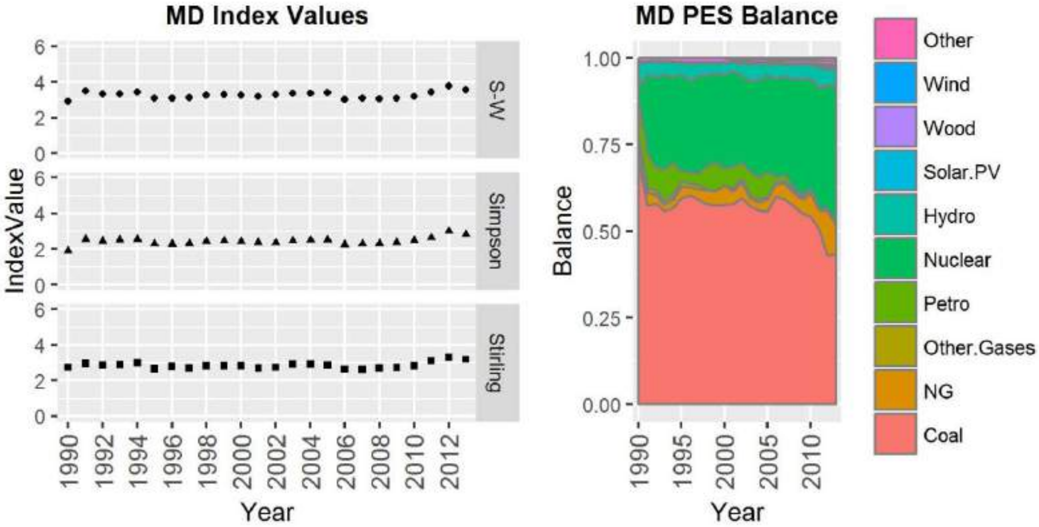


FIGURE SI-21

Diversity and balance trends for Maine.

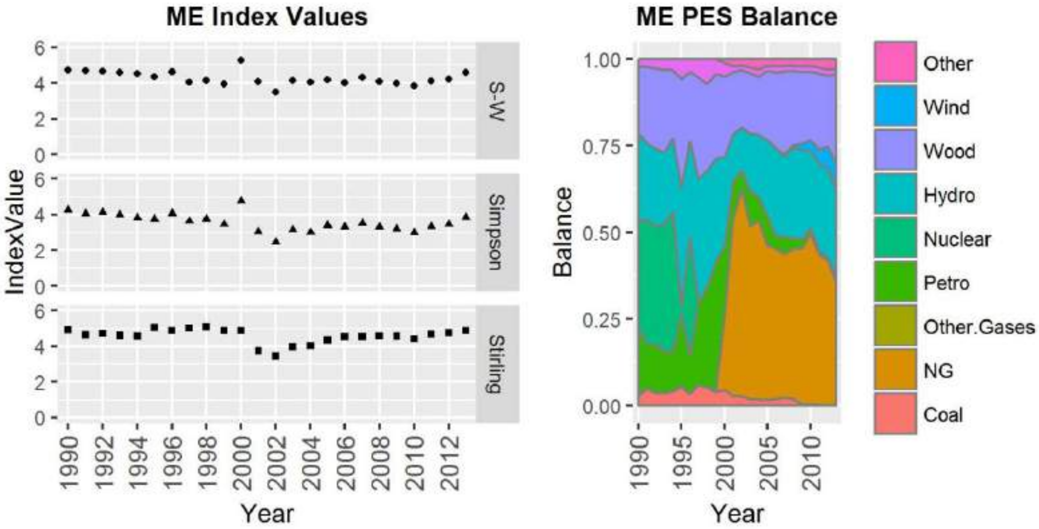


FIGURE SI-23

Diversity and balance trends for Michigan.

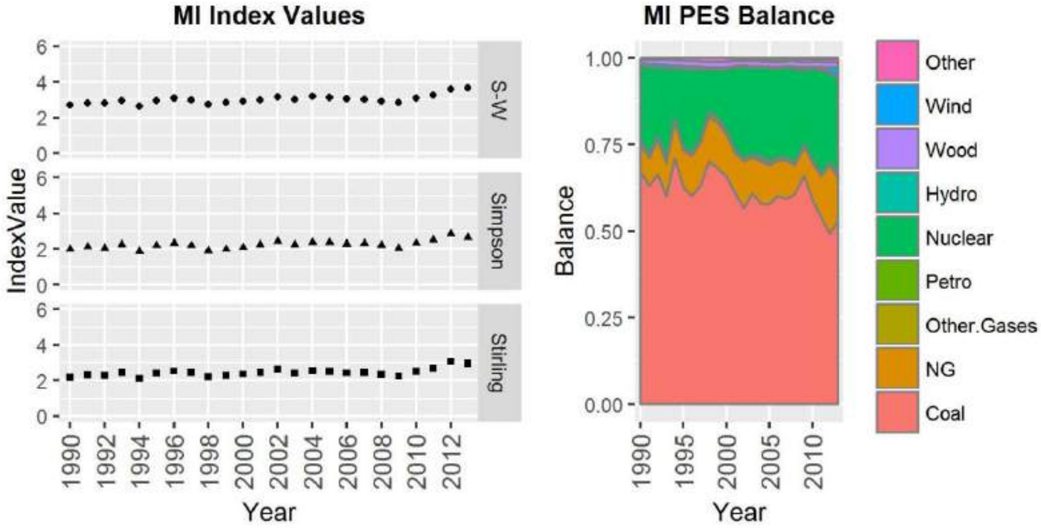


FIGURE SI-24

Diversity and balance trends for Minnesota.

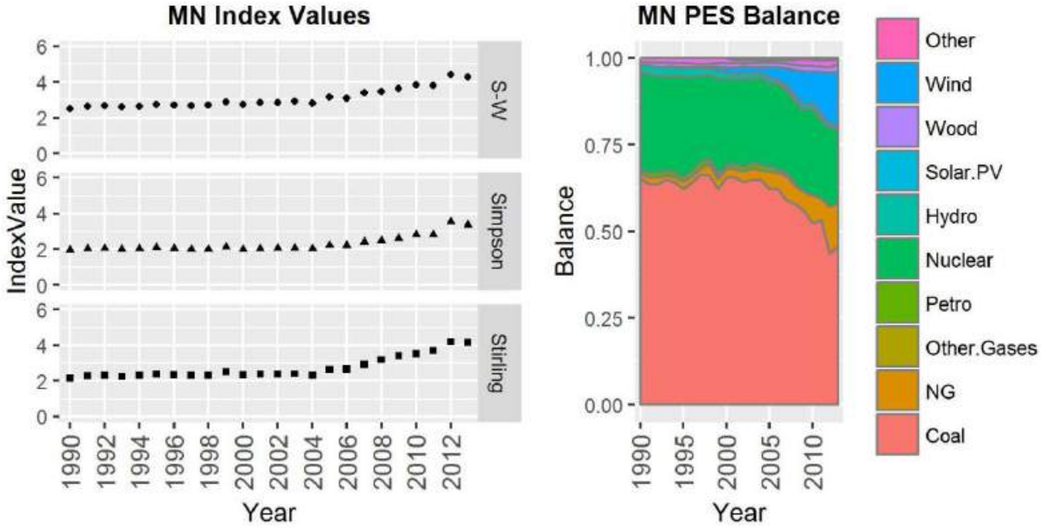


FIGURE SI-25

Diversity and balance trends for Missouri.

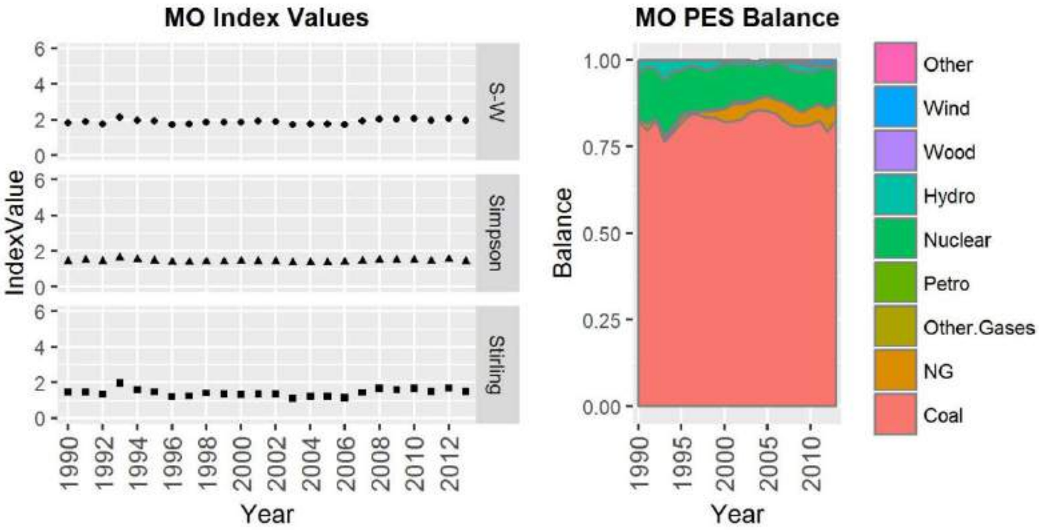


FIGURE SI-26

Diversity and balance trends for Mississippi.

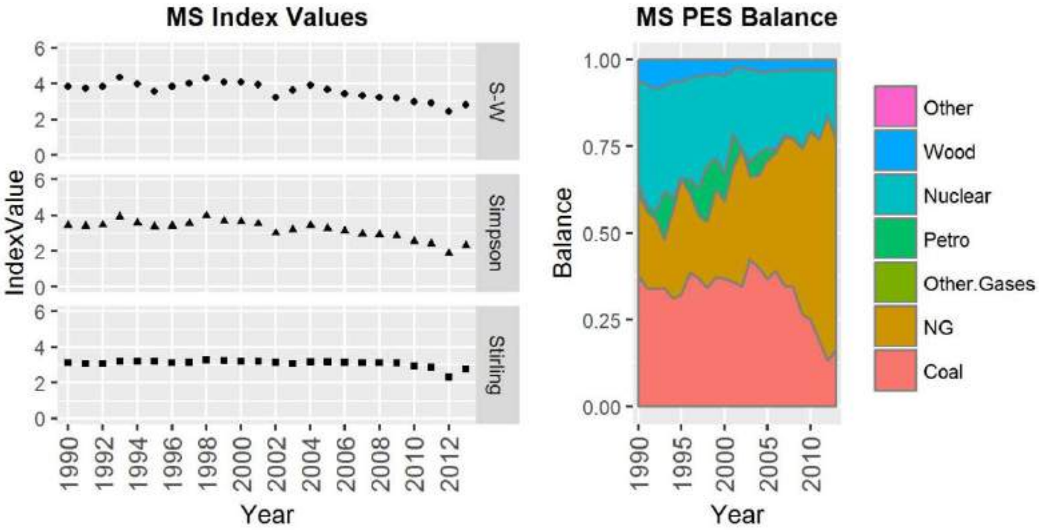


FIGURE SI-27

Diversity and balance trends for Montana.

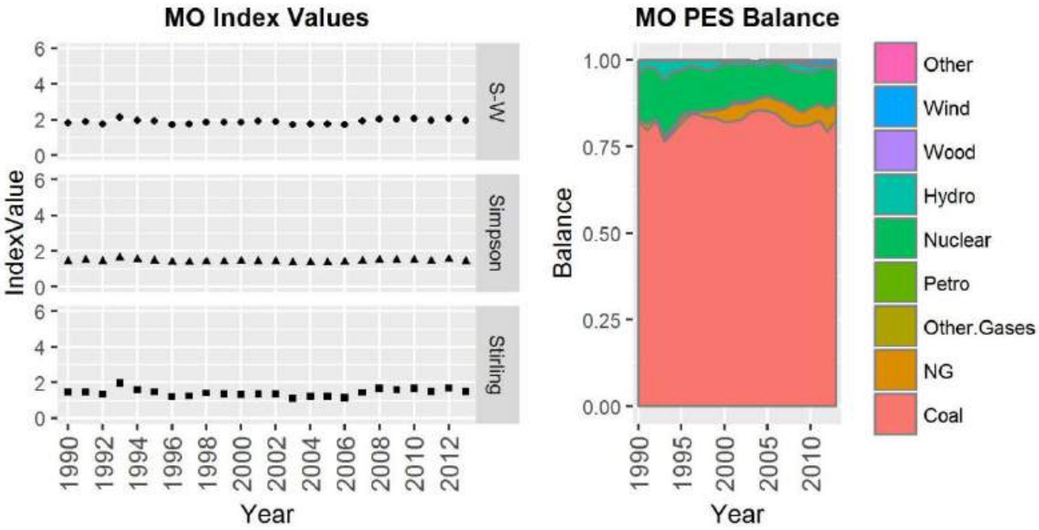


FIGURE SI-28

Diversity and balance trends for North Carolina.

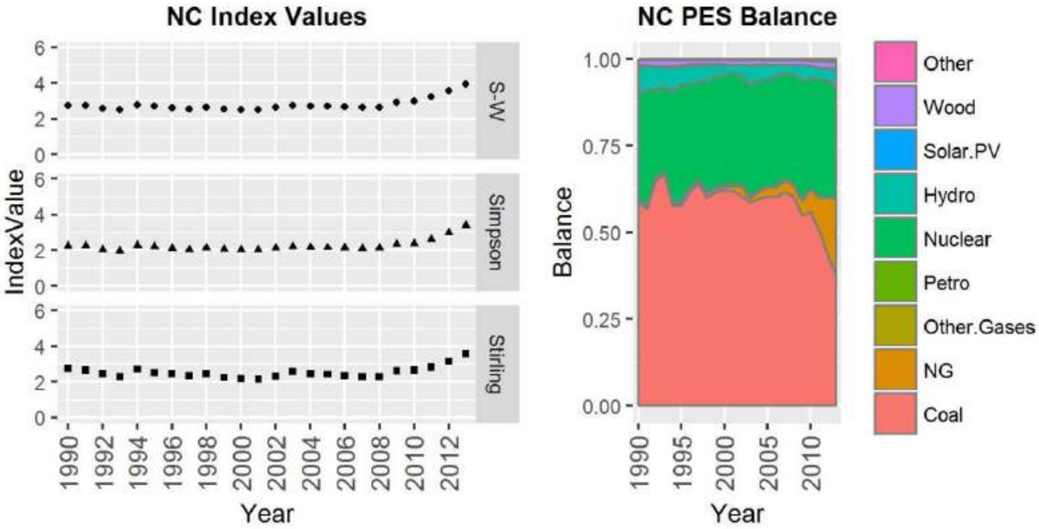


FIGURE SI-29

Diversity and balance trends for North Dakota.

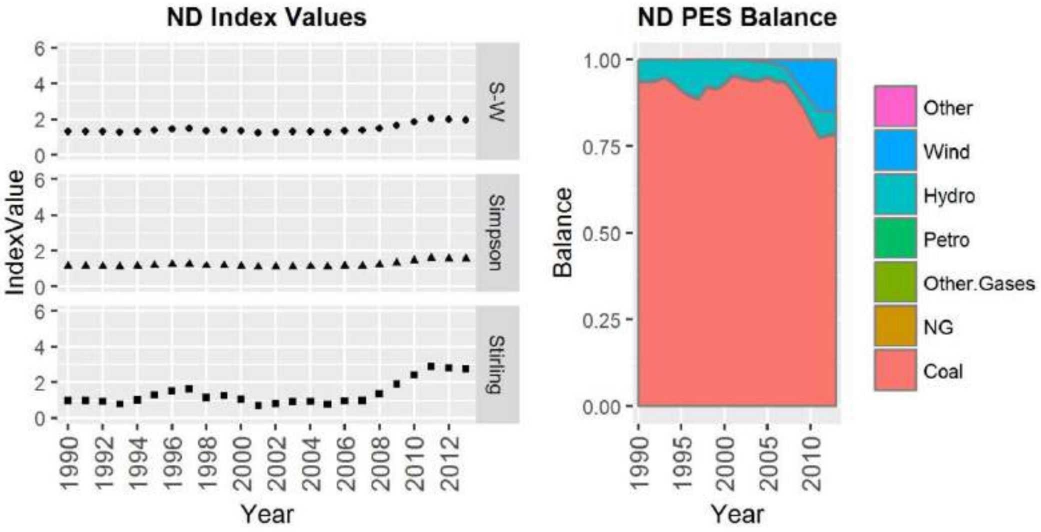


FIGURE SI-30

Diversity and balance trends for Nebraska.

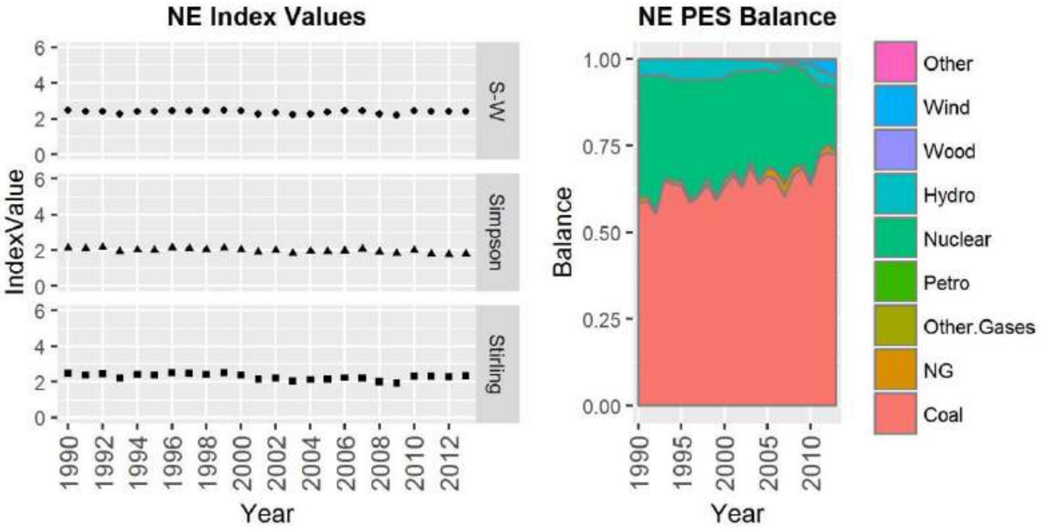


FIGURE SI-31

Diversity and balance trends for New Hampshire.

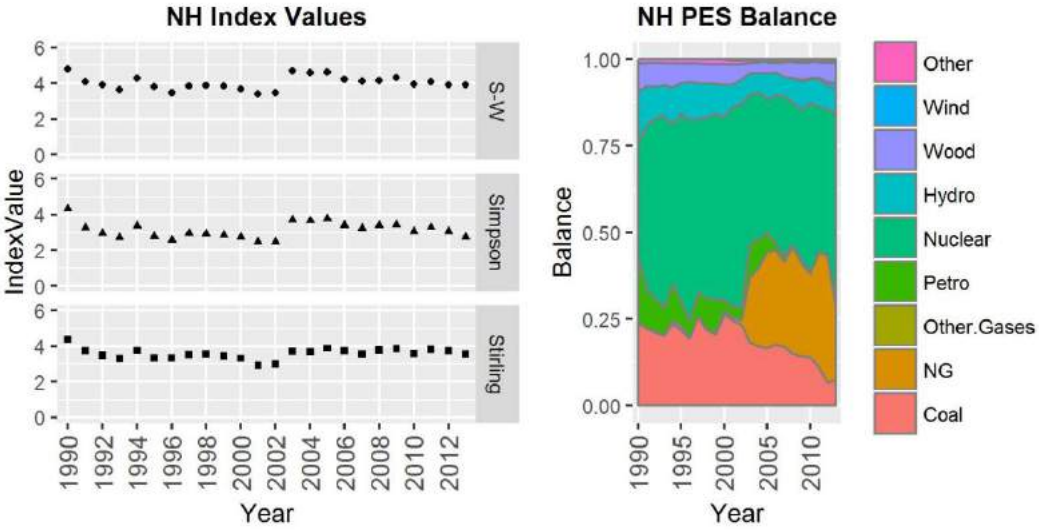


FIGURE SI-32

Diversity and balance trends for New Jersey.

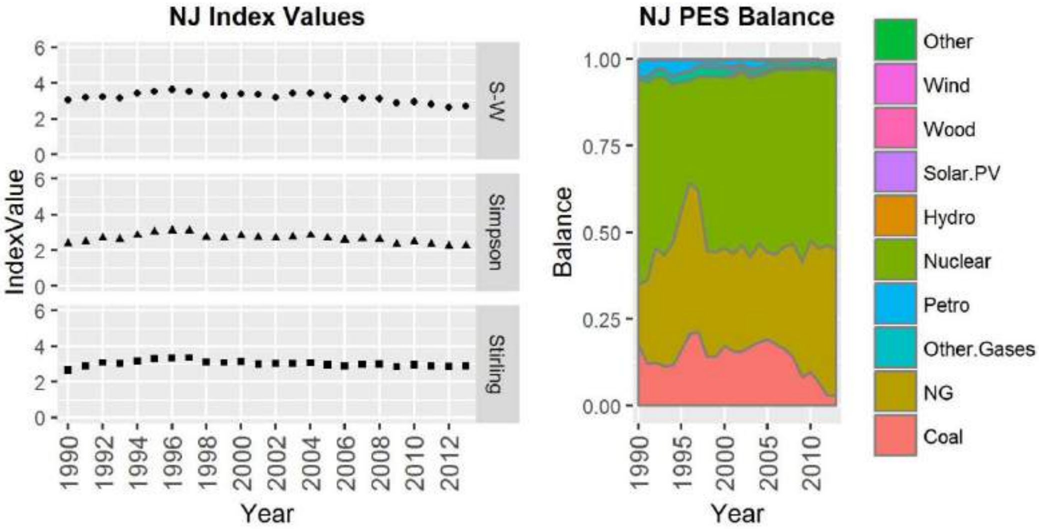


FIGURE SI-33

Diversity and balance trends for New Mexico.

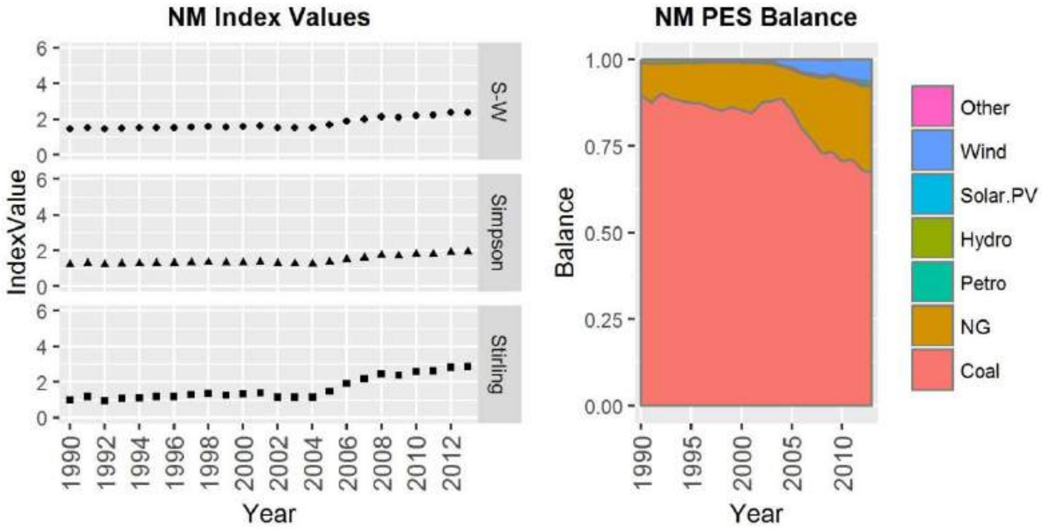


FIGURE SI-34

Diversity and balance trends for Nevada.

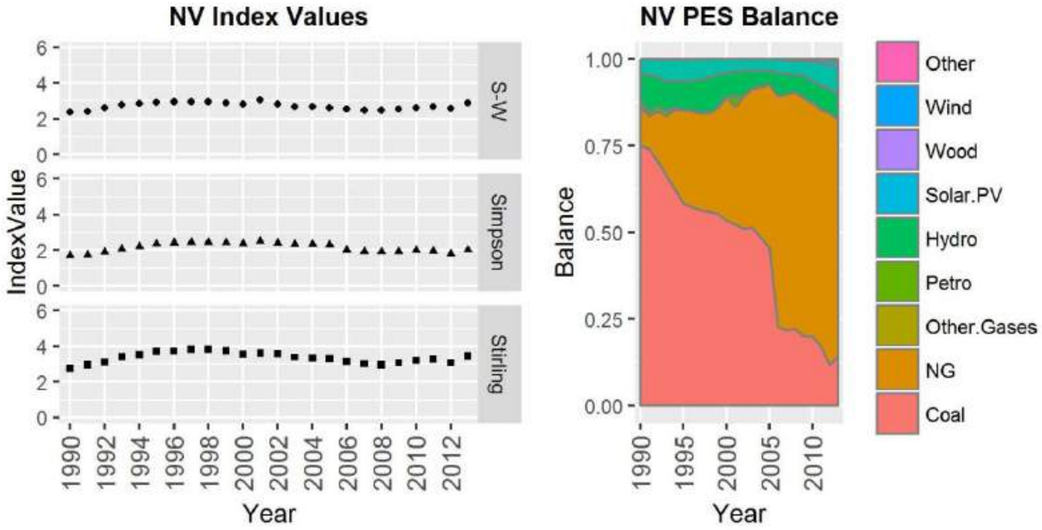


FIGURE SI-35

Diversity and balance trends for New York.

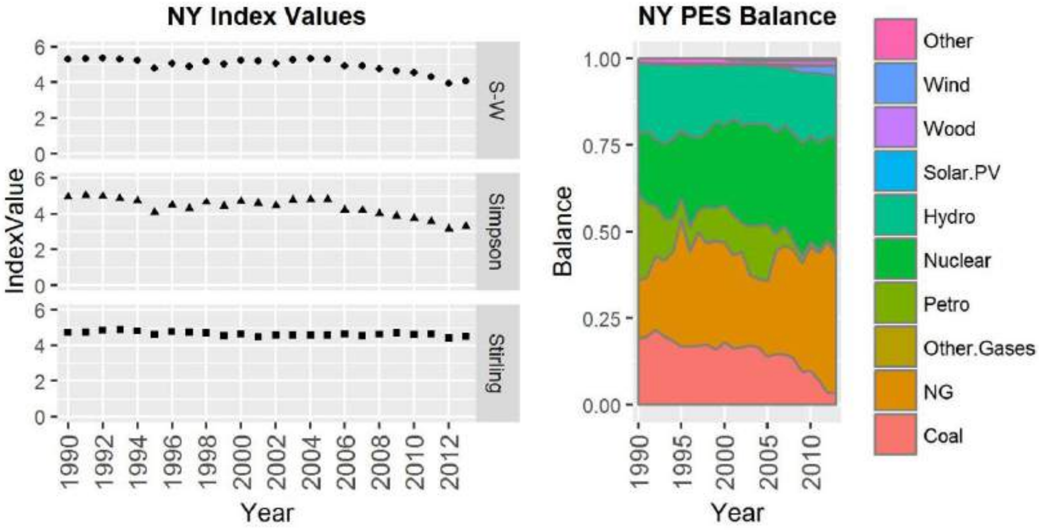


FIGURE SI-36

Diversity and balance trends for Ohio.

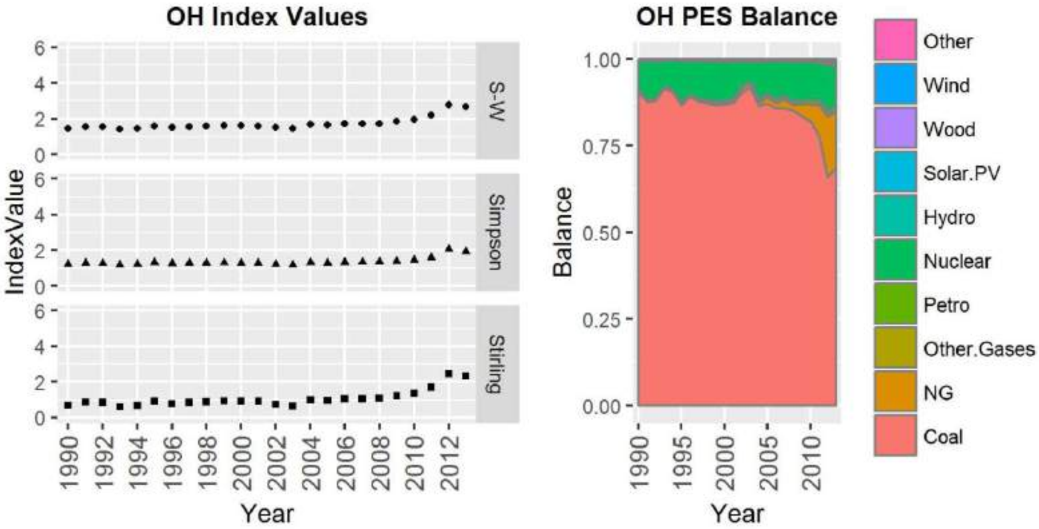


FIGURE SI-37

Diversity and balance trends for Oklahoma.

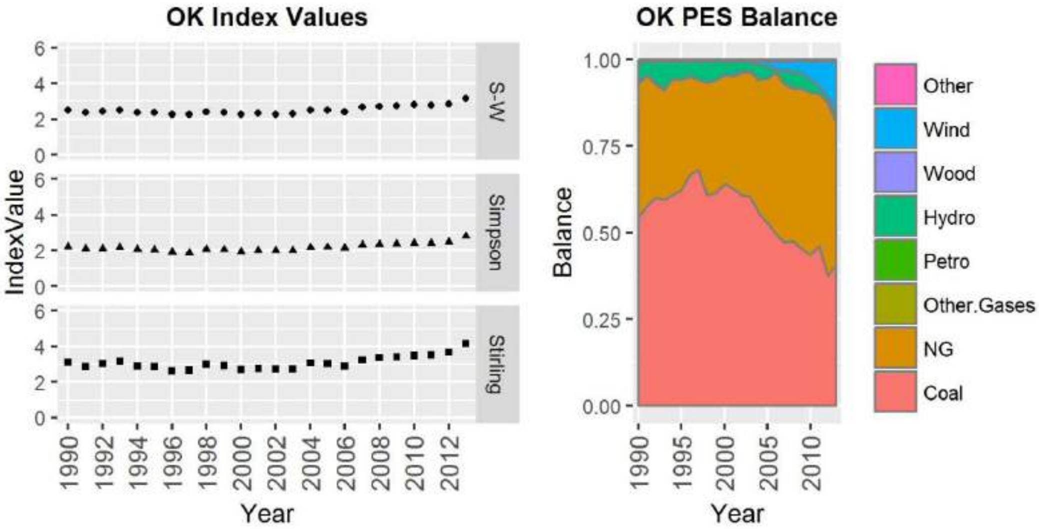


FIGURE SI-38

Diversity and balance trends for Ohio.

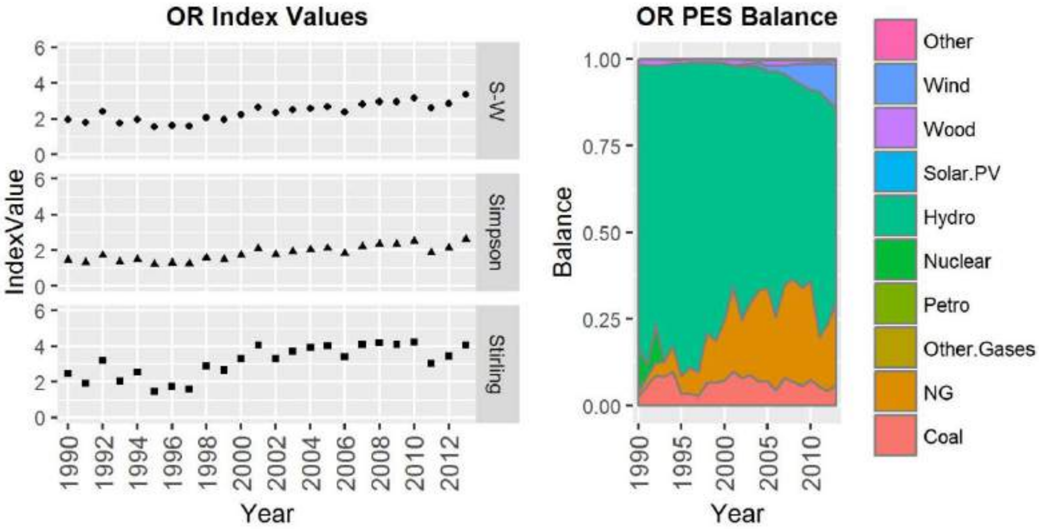


FIGURE SI-39

Diversity and balance trends for Pennsylvania.

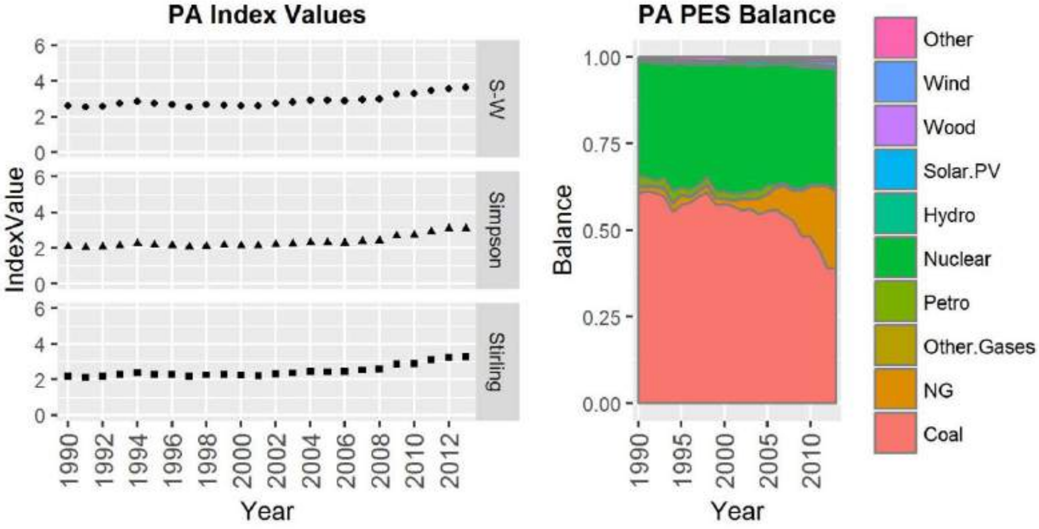


FIGURE SI-40

Diversity and balance trends for Rhode Island.

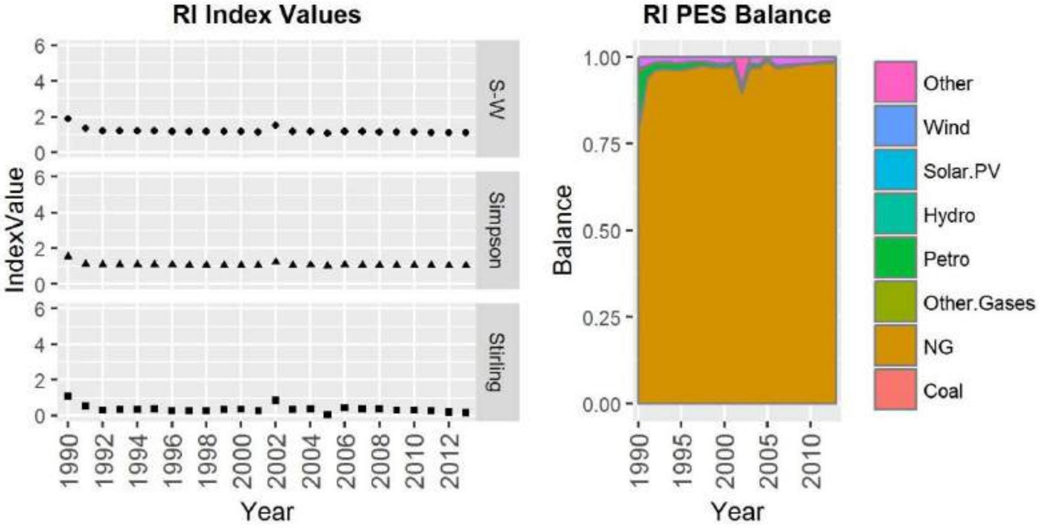


FIGURE SI-41

Diversity and balance trends for South Carolina.

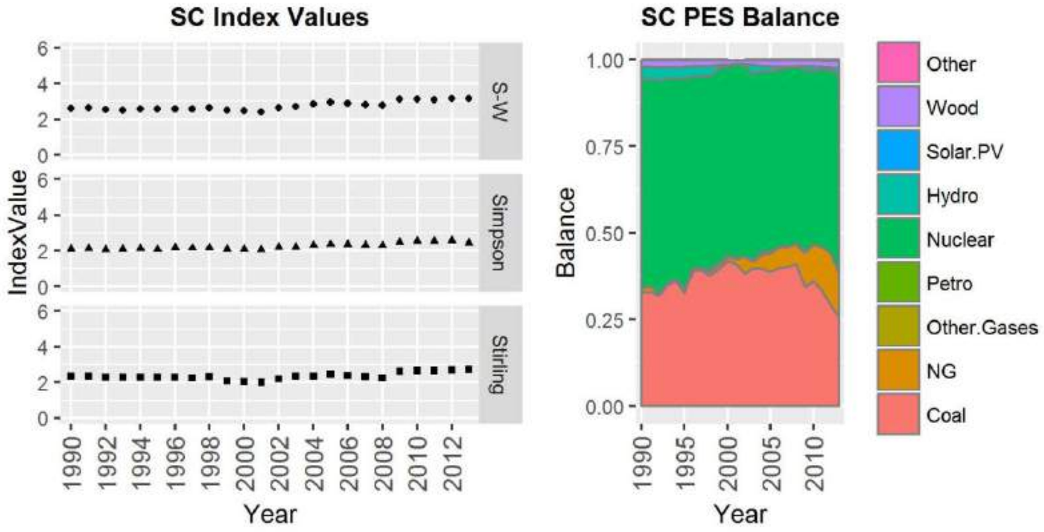


FIGURE SI-42

Diversity and balance trends for South Dakota.

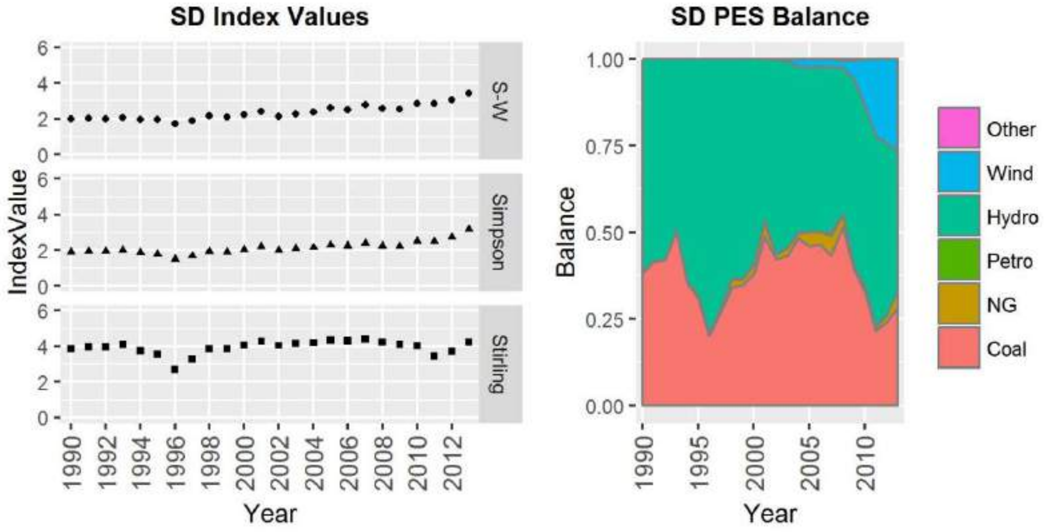


FIGURE SI-43

Diversity and balance trends for Tennessee.

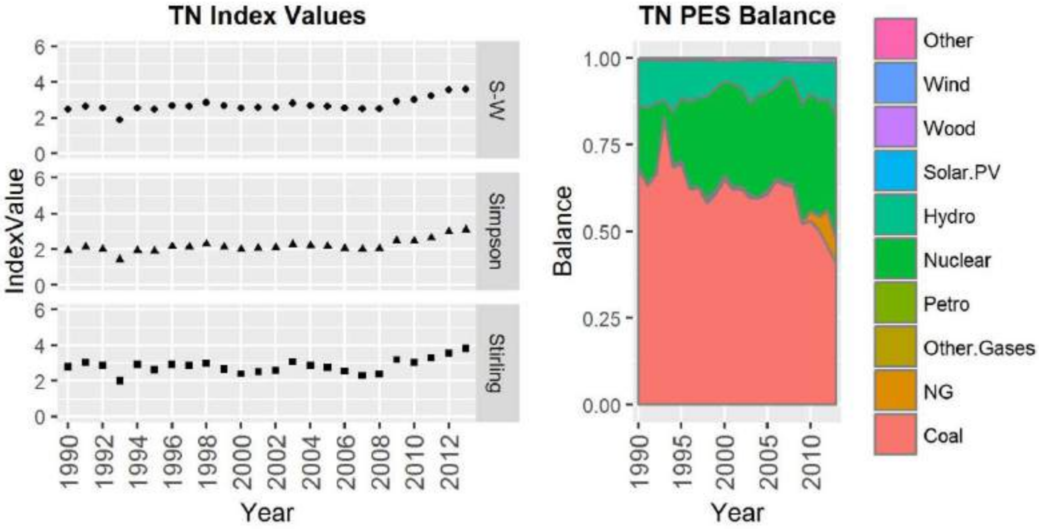


FIGURE SI-44

Diversity and balance trends for Texas.

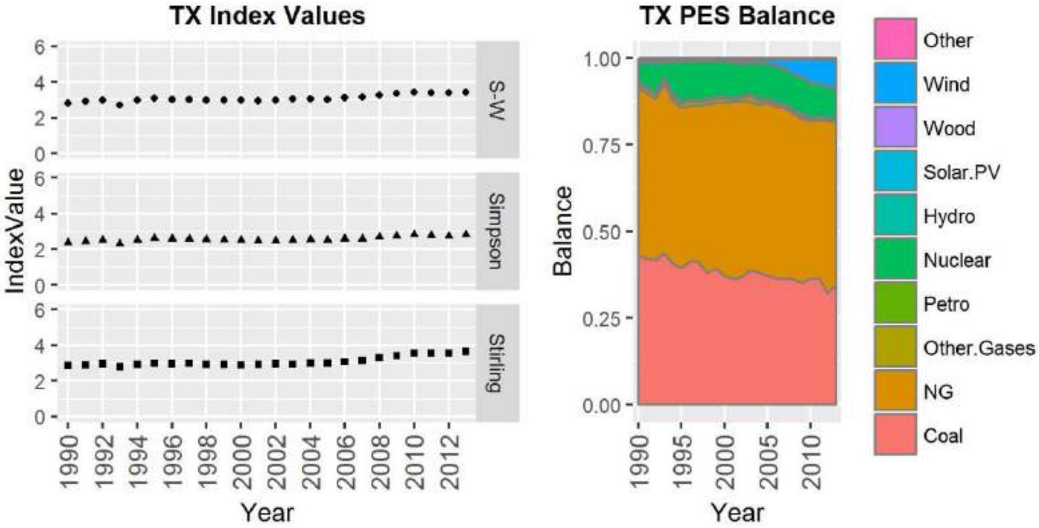


FIGURE SI-45

Diversity and balance trends for Utah.

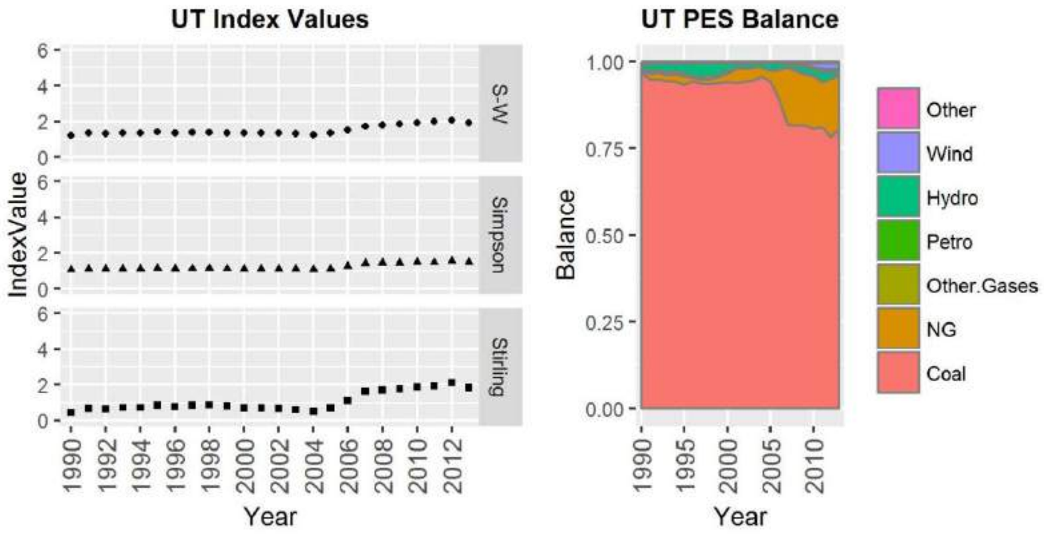


FIGURE SI-46

Diversity and balance trends for Virginia.

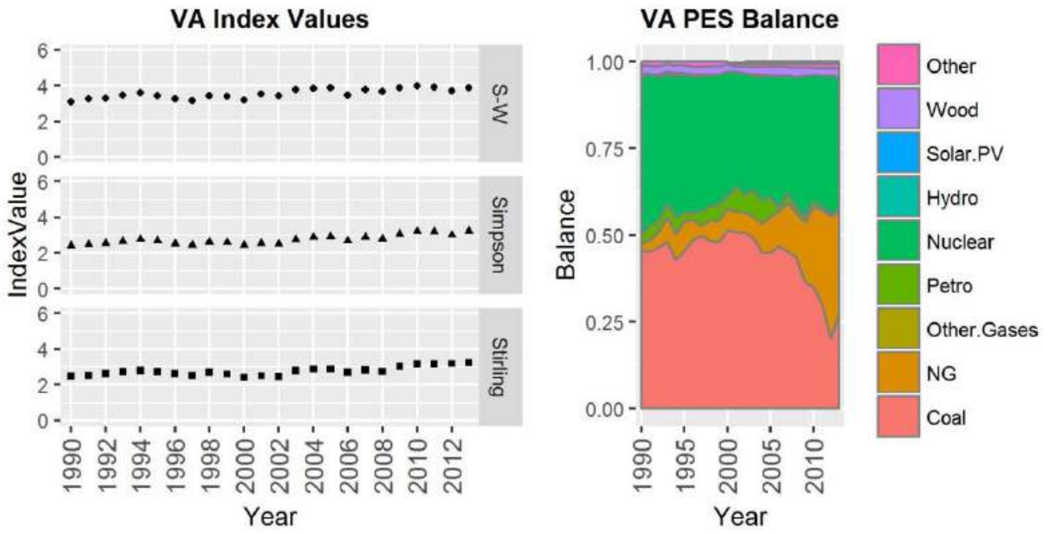


FIGURE SI-47

Diversity and balance trends for Vermont.

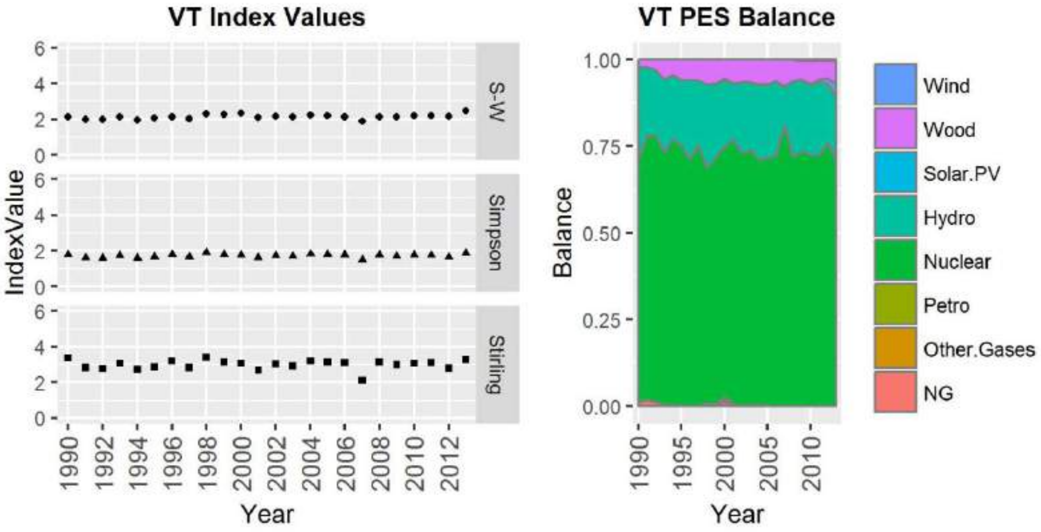


FIGURE SI-48

Diversity and balance trends for Washington.

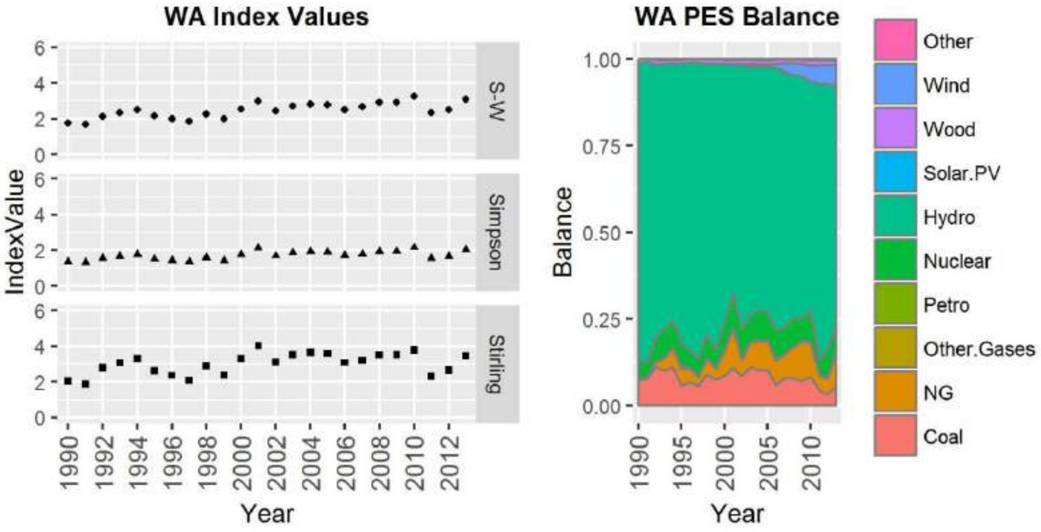


FIGURE SI-49

Diversity and balance trends for Wisconsin.

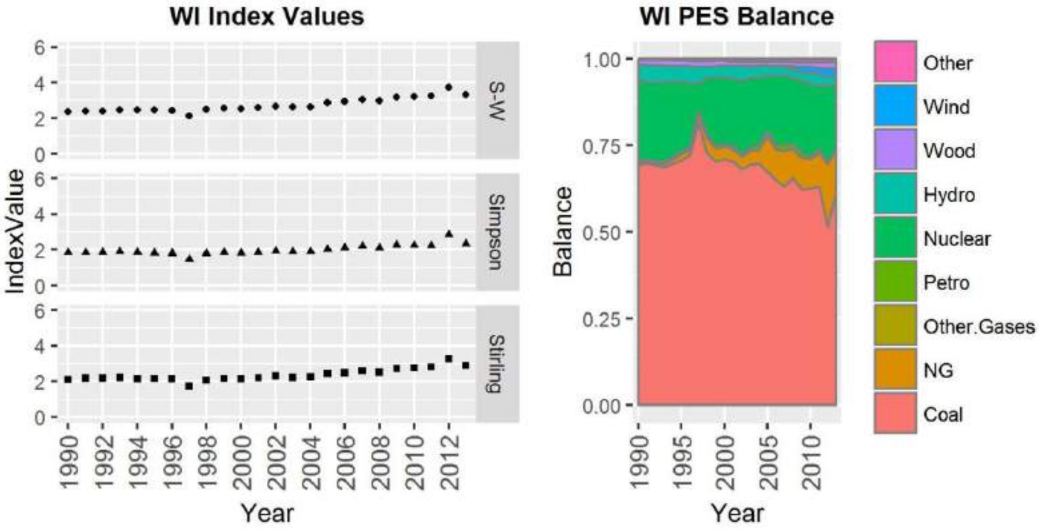


FIGURE SI-50

Diversity and balance trends for West Virginia.

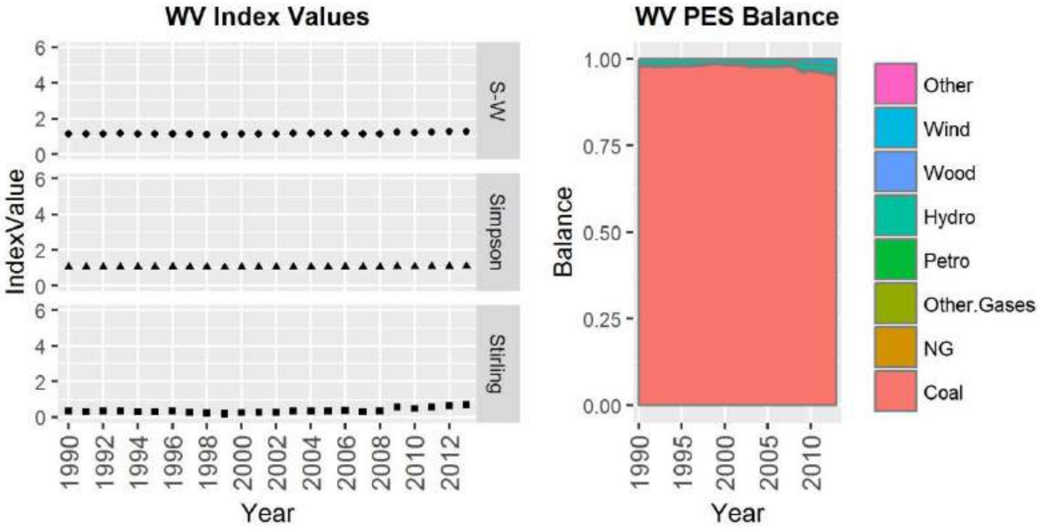
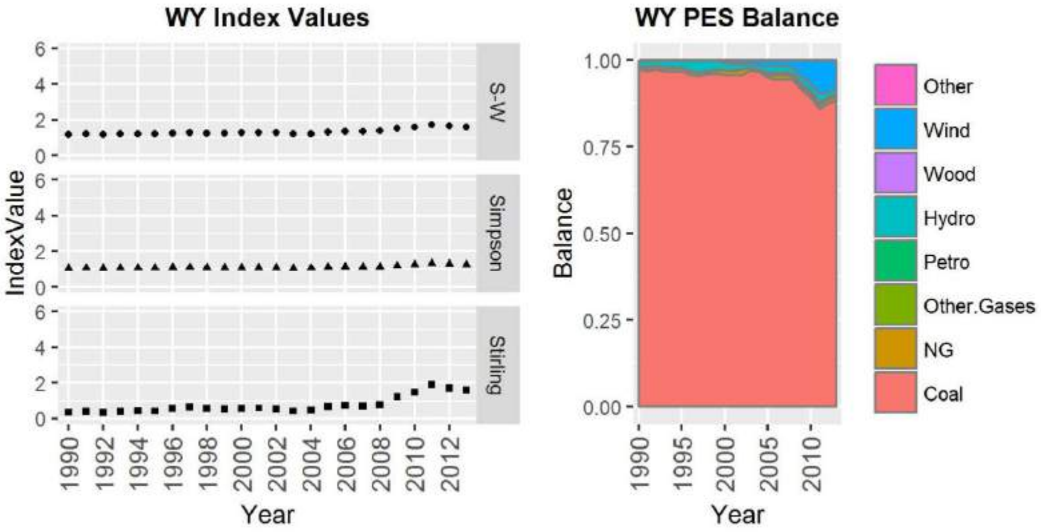


FIGURE SI-51

Diversity and balance trends for Wyoming.



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2. DIVERSITY AND BALANCE TRENDS FOR THE US AND EACH REGIONAL ENTITY

FIGURE SI-52

Diversity and balance trends for the U.S.

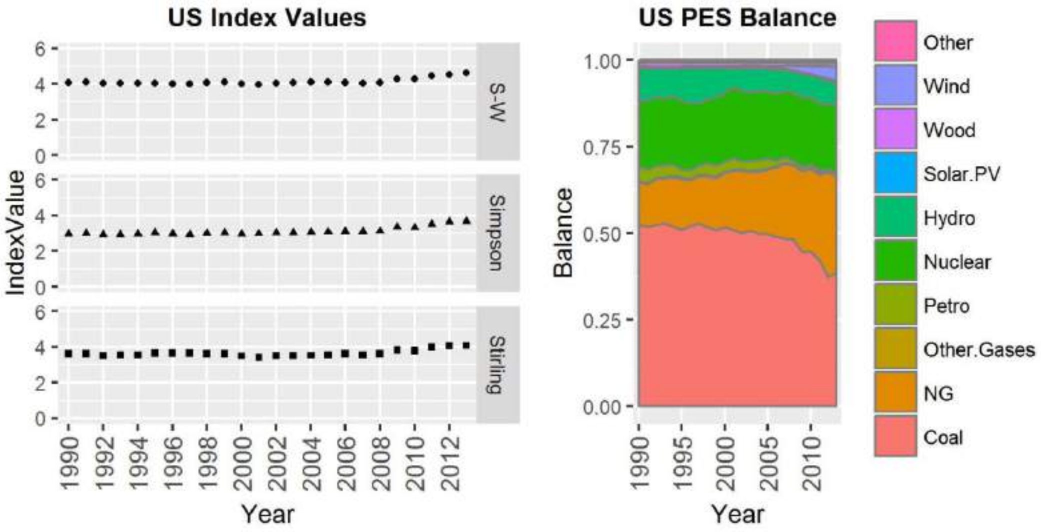


FIGURE SI-53

Diversity and balance trends for Midwest Regional Organization (MRO).

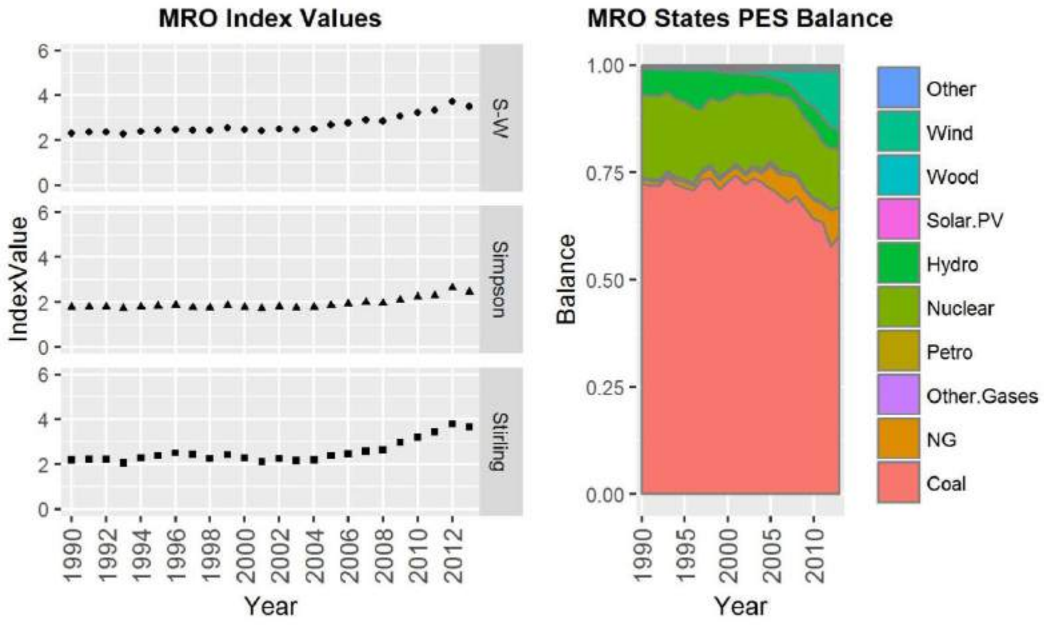


FIGURE SI-54

Diversity and balance trends for Northeast Power Coordinating Council (NPCC).

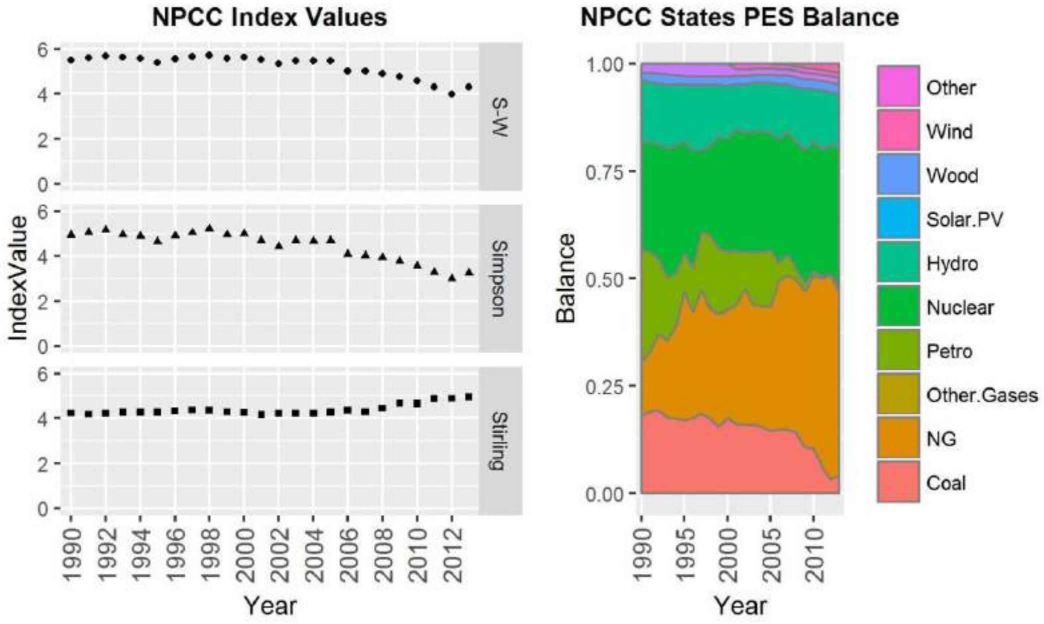


FIGURE SI-55

Diversity and balance trends for Reliability First Corporation (RFC).

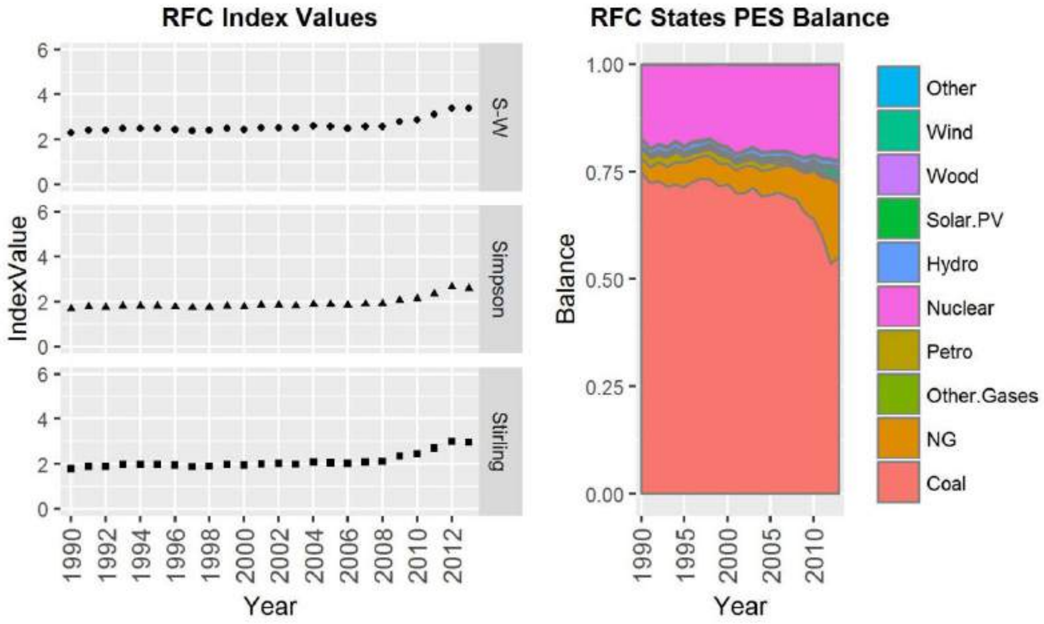


FIGURE SI-56

Diversity and balance trends for Southeast Reliability Corporation (SERC).

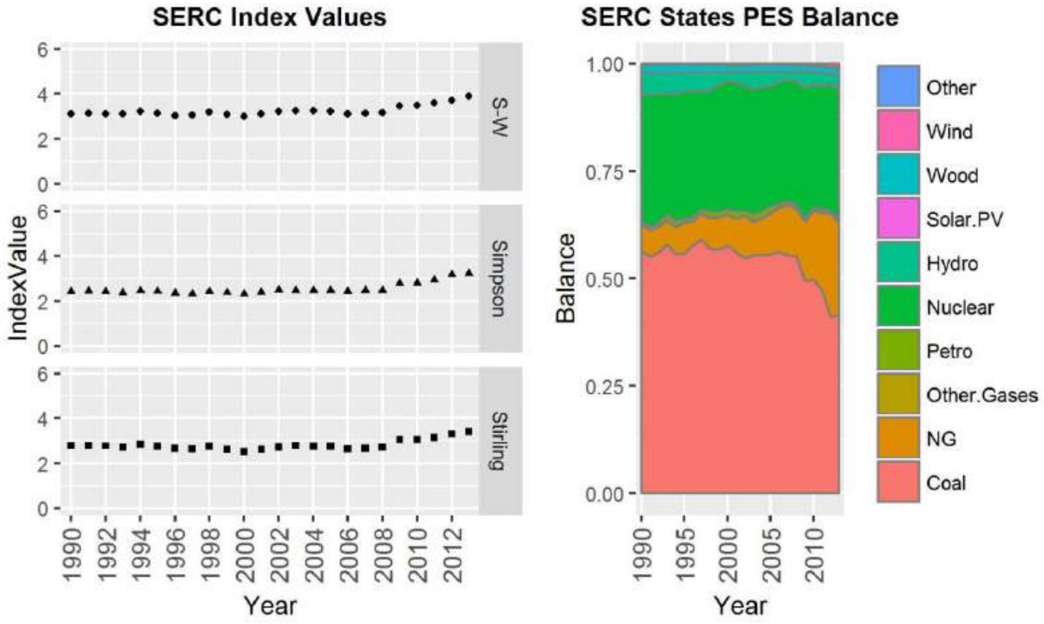


FIGURE SI-57

Diversity and balance trends for Southwest Power Pool Regional Entity (SPPRE).

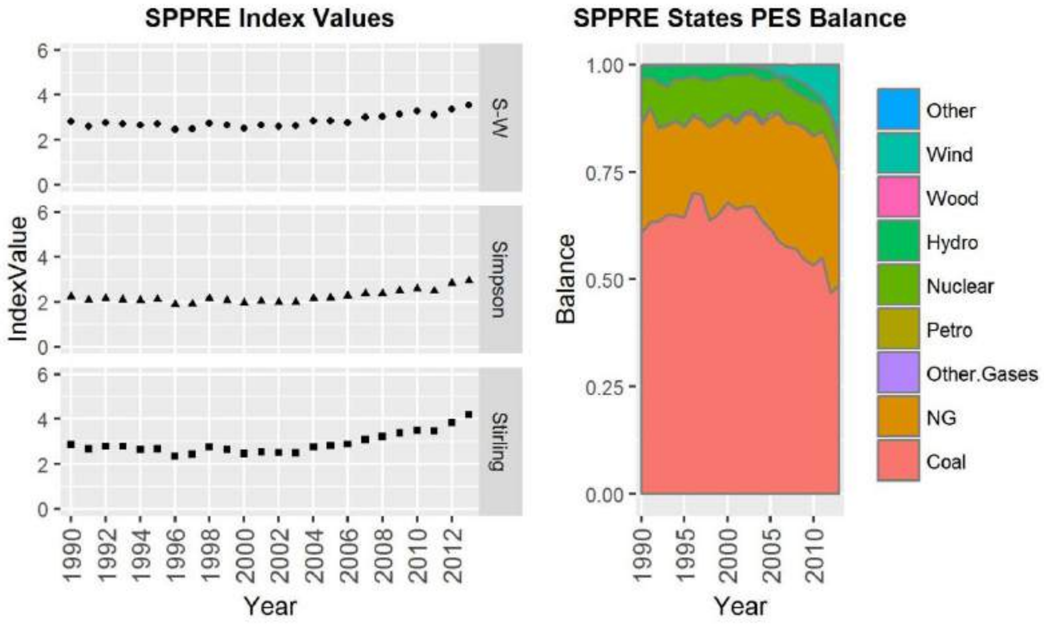
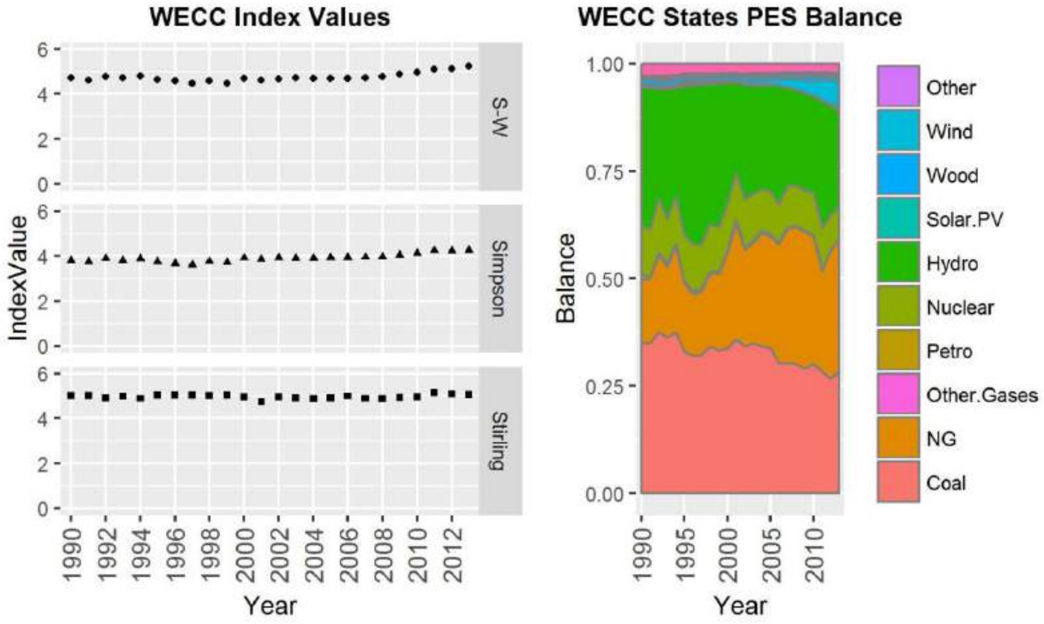


FIGURE SI-58

Diversity and balance trends for Western Electricity Coordinating Council (WECC).



3. DIVERSITY RANKING OF EACH STATE AND THE U.S.

TABLE SI-1

Diversity ranking based on the Shannon-Wiener Index, Simpson Index, and Stirling Index of each state and the U.S. for 1990, 2001, and 2013.

	Shannon-Wiener Index			Simpson Index			Stirling Index		
Rank	**1990**	**2001**	**2013**	**1990**	**2001**	**2013**	**1990**	**2001**	**2013**
1	NY	NY	US	NY	NY	ME	ME	NY	ME
2	CA	MA	ME	NH	MA	US	CA	SD	NY
3	NH	FL	MN	ME	FL	AL	NY	CA	MT
4	ME	CT	CA	MA	MS	NC	NH	OR	CA
5	MA	CA	NY	CA	LA	MN	MT	WA	SD
6	FL	ME	AL	MS	CT	AZ	SD	ME	OK
7	US	US	LA	FL	ME	GA	US	NV	MN
8	MS	LA	NC	US	AZ	NY	MA	AZ	US
9	AR	MS	NH	AR	US	VA	AK	AK	OR
10	LA	VA	VA	LA	DE	SD	AR	MA	IA
11	CT	AZ	AZ	AZ	CA	PA	VT	US	AK
12	AK	NH	GA	CT	NJ	TN	AZ	MT	AL
13	AZ	NJ	MI	VA	AR	LA	FL	FL	TN
14	VA	AR	PA	NJ	VA	AK	CT	CT	AZ
15	NJ	AL	AK	TX	NV	TX	MS	MS	ID
16	MD	MD	TN	AK	AK	MD	OK	LA	TX
17	TX	AK	MD	NC	NH	OK	LA	NJ	KS
18	NC	DE	MA	OK	AL	AR	AL	AL	NC
19	AL	NV	AR	NE	TX	NH	TX	TX	NH
20	MI	MI	SD	SC	MD	MI	TN	NH	CO
21	SC	WA	TX	PA	MI	OR	NV	AR	WA
22	PA	TX	OR	DE	SD	CA	NC	ID	GA
23	GA	MN	WI	IL	IL	ID	MD	DE	NV
24	DE	GA	ID	AL	PA	SC	NJ	OK	PA
25	OK	OR	OK	MI	WA	MT	VA	MD	VT
26	MN	PA	SC	GA	OR	IL	NE	VT	VA
27	TN	WI	WA	MT	TN	CT	OR	TN	MD
28	NE	TN	FL	MN	GA	WI	DE	VA	AR
29	WI	NC	MT	TN	SC	IA	SC	MI	LA
30	NV	IL	HI	SD	NC	MS	GA	MN	CT
31	KS	SC	IA	MD	MN	KS	PA	PA	MA
32	IL	SD	NV	WI	OK	NJ	MI	WI	MI
33	VT	OK	KS	KS	NE	FL	MN	HI	HI
34	MT	NE	CT	VT	WI	MA	WI	GA	WI
35	SD	HI	MS	NV	KS	CO	WA	IL	NJ
36	OR	KS	IL	RI	MT	WA	IL	NC	NM
37	RI	ID	CO	OR	VT	NV	KS	NE	MS
38	MO	VT	NJ	MO	HI	OH	MO	CO	ND
39	WA	MT	OH	WA	ID	HI	HI	SC	SC
40	IA	CO	VT	IA	CO	NM	IA	KS	FL
41	HI	MO	NE	NM	MO	VT	RI	NM	IL
42	NM	IA	NM	HI	NM	NE	CO	MO	NE
43	OH	NM	DE	OH	IA	DE	NM	IA	OH
44	CO	OH	ND	CO	OH	ND	ND	OH	UT
45	ID	UT	IN	ND	UT	UT	ID	KY	DE
46	ND	IN	MO	ID	IN	MO	OH	ND	IN
47	IN	KY	UT	KY	KY	IN	KY	UT	WY
48	KY	WY	WY	IN	ND	WY	IN	WY	MO
49	UT	ND	KY	UT	WY	KY	UT	IN	KY
50	WY	RI	WV	WY	RI	WV	WY	WV	WV
51	WV	WV	RI	WV	WV	RI	WV	RI	RI
52	DC	DC	DC	DC	DC	DC	DC	DC	DC

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U.S. Energy Information Administration. (n.d.). Table T10. Class of ownership, number of consumers, sales, revenue, and average retail price by state and utility for all sectors. Retrieved April 19, 2016, from U.S. Energy Information Administration website: http://www.eia.gov/electricity/sales_revenue_price/

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