# Next Steps

Creat import dependency map layers for each year.

Map the Import Dependency results

Map the Import Diversity results.

Consider counting # of HV connections (and incorporate voltage ratings of each connection) to neighbors by BA (from HILFD network data overlain with BA shapefile?)

Come up with a way to analyze import availability during extreme periods (e.g. highest net load period) by BA.

Do a generic broad analysis on import dependency during highest net load periods

Do a case-study approach that looks at import performance etc during selected extreme events in certain BAs

* Winter Storm Uri in Texas
* As the events of August 2020 in California and February 2021 in Texas demonstrate, supply shortfalls can have large economic and public health consequences

# Introduction

* Explain how reliability has become more of a concern today than it historically has been.
  + Today’s system: increasing variable supply like wind and solar and Retiring conventionanl generation.
  + Electrification and demand growth
  + Extreme events (increasing?)
* Understandably, planning approaches to ensure sufficient resources available to serve demand across the full year and under stressful grid conditions is an active area of research. *(opportunities for unused citation dump)*.
* One important component of this that is understudied is the role of imports in supporting future reliability for individual systems.
  + Difficult question: depending on the system, imports may play a significnat role in supporting reliability during stressful conditions, but is more uncertain than reliance on local resources. Imported resources are generally outside the direct of the local planning entity and depend on excess capacity in neighboring systems.
* Given the increased uncertainty associated with availability of imports, system planners may discount or not consider their contributions to reliabiltiy in future plans. (now transitioning to that nice Larsen 2023 quote)
* A crucial question to address in this research is “how should planners consider availability of imports from a capacity adequacy perspective in long term plans ? Larsen 2023 says it should be decided by policymakers and not individual market participants:

*We conclude that policy makers can go into one of two directions. The first option is to ignore cross-border trading in their planning. While this would create security of supply for individual countries, it would come at the cost of very significant investment subsidies. The alternative is to rely on cross-border trade, an option which requires not only close cooperation and coordination, but also significant trust between the jurisdictions and institutions involved, to ensure sufficient capacity. The choice between these options is a political decision, to be made at the national and supranational levels, not by regulators, and even less by market participants.*

*Some [Newberry (2016)] make the case that capacity of interconnecitons with neighboring systems and the reliance on imports for reliabiltiy shoult be recognized in planning.*

*But how or by what method can one determine the level of capacity that can be relied on when needed?*

Analysis at BA level. Not much research done at this scale. Etc.

* Balancing Authority: *The responsible entity that integrated resource plans ahead of time, maintains Demand and resource balancing wihin a Balancing Authority Area, and supports Interconnection frequency in real time*
* Balancing Authority Area: *The collection of generation, transmission, and loads within the metered boundaries of the Balancing Authority. The Balancing Authority maintains load-resource balance within this area.*
  + [Glossary\_of\_Terms.pdf (nerc.com)](https://www.nerc.com/pa/Stand/Glossary%20of%20Terms/Glossary_of_Terms.pdf)

# Import Reliance

Import reliance is defined as the fraction of domestic consumption covered by net electricity imports over a period. This is a simple metric that is easy to interpret and commonly identified in the research literature on electricity supply security [1–4], sometimes also referred to “import dependence.”

Figure 1 displays import reliance by balancing authority. In general, it shows the areas in the U.S. with relatively higher levels of imports include the Northwest, Southwest, and Northeast. The highest levels of import reliance from 2016-2023 were among BA’s in the Northwest U.S. Specifically, Portland General Electric Company, Puget Sound Energy, and the City of Tacoma Department of Public Utilities had the highest shares of imports at 0.70, 0.57, and 0.48, respectively. Nearly all the imports into these three regions came from the Bonneville Power Administration BA.

A map of the united states

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Figure 1 Import reliance as a share of total electricity consumption by U.S. Balancing Authority, 2016-2023.

There are a few additional import-dependent BA’s shown in Figure 1 that appear to be outliers relative to their neighbors. El Paso Electric Company in southwest Texas was 44% reliant on imports over the sample time period; 67% of its imports were from Public Service Company of New Mexico and 30% from Tuscon Electric Power.

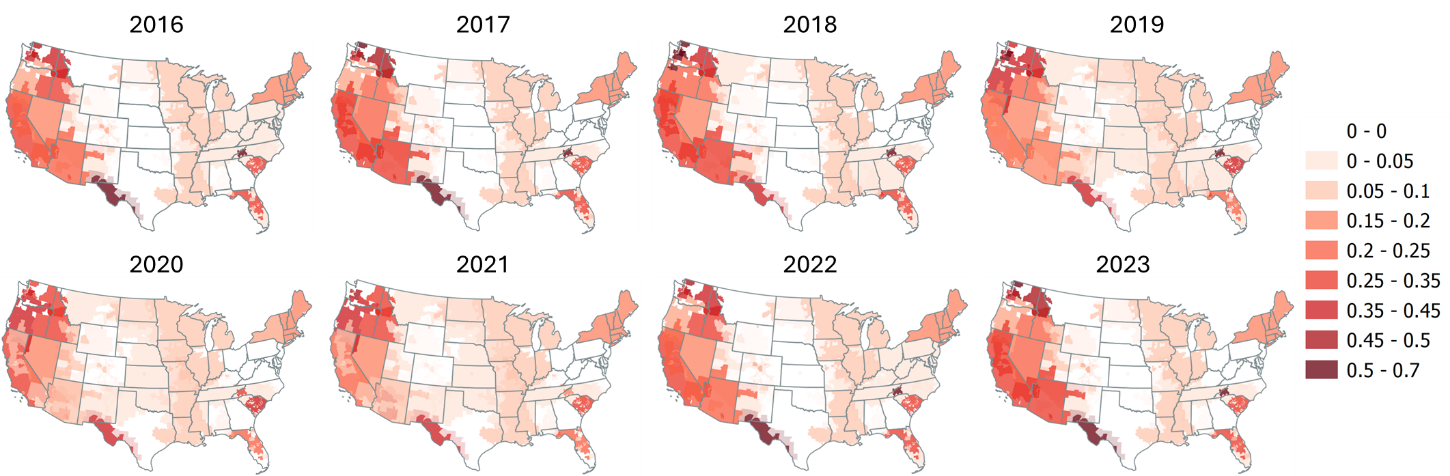
Duke Energy Progress (DEP)in the Carolinas is administratively split into two BAs in the west and the east part of its footprint. DEP west is 42% reliant on imports and significantly smaller than the DEP east. The majority of DEP west imports come from its neighboring Duke-controlled BAs. In this way, the high level of import reliance DEP west may not reflect significant import reliance risk from the perspective that Duke as a parent company likely owns and controls much of the resources being traded across the multiple BAs it administers in the Carolinas.

Duke Energy Florida (DEF) is also relatively import-reliant at 24% compared to its neighboring BAs. It is relatively diverse in its sources of imports and, unlike the Duke BAs in the Carolinas, does not trade with company affiliates. Rather, 32% of its imports were from Florida Power & Light, 26% from Florida Municipal Power Pool, 24% from Seminole Electric Cooperative. It also receives smaller levels of imports from Gainesville Regional Utilities, Southern Company, and Tampa Electric Company.

* CAISO and ISONE + NY in NE are relatively import dependent regional transmission organizations, where are those coming from?
* In contrast, PJM and ERCOT have quite low reliance on imports
* Note the average and range of the weighted national average import reliance.
* Note relatively stable and no discernible trend in import reliance from 2016, 2023.
* Noticable drops in 2018 and 2023 (any insight?) RECHECK THIS TABLE

*Table 1 Demand-weighted average of import reliance by year for U.S. Balancing Authorities.*

|  |  |
| --- | --- |
| Year | Import Reliance |
| 2016 | 0.067 |
| 2017 | 0.070 |
| 2018 | 0.070 |
| 2019 | 0.066 |
| 2020 | 0.070 |
| 2021 | 0.072 |
| 2022 | 0.070 |
| 2023 | 0.069 |
| 2024 | 0.064 |



*Figure 2 Import reliance for U.S. Balancing Authorities by year.*

* Note and analyze variation in NW and CAISO import reliance, significant inversions between 2018-2019, and 2021-2022. Do these have any relation between hydro production levels that vary over years?
* Note and analyze variation in SPP’s import levels. Why is that change noticeably by year and which trading partners are the change drivers?

The import reliance metric is simple to calculate and interpret and provides an accurate perspective on the reliance of a balancing authority on electricity supply physically located outside its territory. In this way it presents a useful starting point for an analysis. It is important to note that “import reliance” is not necessarily a concern- there are likely good reasons when a BA imports electricity to supply local demand. Many studies have shown economic efficiency gains from trade available when two regions integrate electricity trade [5–10]. From this literature, one may conclude that any BA’s not relying on imports are leaving economic efficiency opportunities on the table. However, the magnitude and characteristics of electricity trade efficiencies vary depending on the underlying characteristics of individual systems, including resource mix, demand characteristics, and geographic traits.

There are also reasons why expanding regional electricity trade could be more costly than the available benefits. One potentially significant barrier is if the physical links connecting two BAs are already congested, alongside the sometimes-prohibitive cost of building new electric transmission lines [11]. Others include the fact that integration and associated regional efficiencies associated with electricity price equalization will produce some losers underlying the total economic improvements to the region [12]. Potential losers from regional integration include electricity customers facing higher costs in exporting BAs and producers facing reduced profits in importing BAs [13]. Other factors to consider for a better understanding of the observed trading situation between neighboring BAs are the political relationship between the regions, market trading rules, and other institutional realities that could create to trading friction or other sources of risk associated with expanded trade [14]. Sometimes regional integration is accompanied by efforts to expand BA territory, which can involve an expansion of centralized control over dispatch and resource adequacy to a grid operator in one of the regions. It is sometimes tempting to analyze and pursue trading opportunities from an economic efficiency lens without considering the potentially significant political cooperation needed as a foundation for lasting economic integration [15,16].

Furthermore, the import reliance metric is limited in assessing reliability risk is that it does not account for relevant characteristics of the contractual arrangements underlying electricity imports. For example, a balancing authority whose imports are provided under firm delivery arrangements may have lower reliability risk than a BA that relies on significant imports purchased from a spot market.

The import reliance metric also does not incorporate the diversity of external sources of supply, which is a relevant factor for assessing reliability risk. A region relying on imports may be more reliable if it has many different sources of external supply. In contrast, a balancing authority that is heavily reliant on imports from a single large plant may have higher risk. A similar perspective that is not captured in the import reliance metric is the number of interconnections over which electricity imports flow into the BA of interest. A region reliant on imports over a single transmission line has greater reliability risk than one with multiple lines providing some redundancy if one experiences an outage. These two perspectives are analyzed further for U.S. BA’s in subsequent sections.

# Import Diversity

*Draft some text that motivating the importance of a BA electricity import diversity could be useful indicator from a Resource Adequacy perspective.*

*Another paragraph or few sentences bringing us to the concept of formal diversity metrics and in particular the Shannon Index.[[1]](#footnote-1)*

|  |  |  |
| --- | --- | --- |
|  |  | *(1)* |

Where is the share of imports from neighboring BA relative to total demand in the system of interest. Mathematically, is inversely related to the geoemetric mean of the relative shares such that a higher value describes a system with a more diverse set of imports.[[2]](#footnote-2)

The Shannon Index has been considered in many energy security-focused studies as a metric for diversity of primary energy and energy import sources [17–30]. Less common are studies utilizing metrics to assess electricity generation diversity [31–34]. This study is the only one the author is aware of that applies these indices to assess electricity import diversity among individual balancing authorities within the United States.

~~UPDATE TO SHANNON Index fo rreasons provided in footnote 13 of Kruyt 2009 A black and white symbol

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~~Stirling (1999) in his elaborate work on diversityfavours the Shannon index over the HH index, based for 2 reasons. First, the~~

~~Shannon index retains rank ordering under variations of logarithm base, whereas~~

~~the rank ordering of different systems changes as the exponent of the Simpson~~

~~index changes. As there is no fundamental argument why the exponent should be~~

~~2, this raises doubts with regard to the ﬁrmness of the results obtained, since by changing an apparently non-related parameter, the outcome will differ. Second,~~

~~the Shannon index displays the property of additivity with respect to taxonomy.~~

~~This means that when classifying options based on several criteria, the index score~~

~~for the system classiﬁed according to criterion a, plus the index score for the~~

~~system classiﬁed according to criterion b should amount to the same as the index~~

~~score for the system classiﬁed according to the combined criterion ab. This is~~

~~mathematically represented as f(ab) ¼ f(a)+f(b), with a and b sets of options under~~

~~different classiﬁcations and f the index or function in question~~

~~In many applications of these concentration or diversity indices, the market share value (p) cannot be greater than one. In our case, it can in situations where a BA is importing more than it consumes. This can occur if a BA’s imports “pass through” to be consumed by another neighbor, generally when it is a small BA that is well-integrated with its neighbors. When this occurs, the Import Diversity metric goes negative, but in our reporting we truncate the value at 0, since a “negative” diversity metric is difficult to interpret. In contrast, a value of 0 “import diversity’ implies that all of the local demand is satisfied by imports from a single neighbor.~~

~~for each neighboring balancing authority importing into the region with total electricity consumption equal to over the period of interest.~~

~~Many studies on energy security utilize a similar diversity (or the inverse for a “concentration” metric) applied to primary sources of energy at the nation-state level. (check Kruyt et al. 2009 as possible citation here, and any others) Cite Kruyt’s approach in the appendix, and a bunch of their citations that apply diversity to fuel supply.~~

~~It doesn’t have the same interpretation when used commonly for market shares, but still gives a relative quantitative comparison of import diversity across BAs.~~

*~~Include some key stats of the HHI distribution so BA’s have something to benchmark their systems agains.~~*

*WALC has a high/funky import dependency value because it is getting lots of power to “pass throguh” BA. Impoting lots from AZ and passing it along as exports to CA (probably the big Nuclear plant). Note this example as (a downside?) special case to keep in mind when evaluating BA import diversity metrics for BA’s that “pass through” lots of power for economic reasons,.*

AZPS stopped producing nuclear at the end of 2019 in the data, went from an exporter to an importer at this time. It appears maybe Palo Verde was double counted in both AZPS and SRP, and then AZPS stopped including it at the end of 2019, while SRP continud reporting the full Pverde output in its BA.

This leads to a caveat with use of Balancing Authority definition and BA-level metrics, that it may not capture the nuances of the imports situation for multiple BA’s that are well integrated, or have firm contractual rights to capacity physically outside its borders.

# HVDC Interconnectors

# Imports during stressful events

# Other Data characteristics

Hourly Demand and interchange variables can cover 2016-2023

Generation by fuel type covers 2018-2023

# Balancing Authority Shapefile

Balancing area shapefiles were used from Homeland Infrastructure Foundation-Level Data (HIFLD)’s “Control Areas” dataset [35].

# Literature review and discussion

* From a reliability perspetive, it is important to evaluate how “import dependent” BAs operate during times when demand is highest and/or the available supply and reliability of the grid is stretched near the limit.

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1. The Shannon Index was originally proposed in Claude Shannon’s foundational communication theory paper to define a concept of entropy in the context of transmitted information [36]. Since then, it has been applied as a measure of diversity for a range of applications, notably for species diversity in ecologic systems [37–39]. [↑](#footnote-ref-1)
2. Specifically, it can be derived that 1eH is the geometric mean of the relative shares pi [40]. From this relationship, a relatively concentrated (less diverse) pi set leads to a higher geometric mean and a lower H value. Find the source and do the derivation [↑](#footnote-ref-2)