Characterizing Stranded Power in the Electric Reliability Council of Texas (ERCOT) in Years 2012-2019: A Preliminary Report

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Following prior studies [2, 3], we characterize the phenomenon of stranded power (curtailed and low-priced power) in the ERCOT dispatch region. This study analyses data from 2012 through 2019, spanning both the introduction of the CREZ and three-fold growth of wind generation.

The analysis shows that stranded power in the ERCOT grid is a persistent phenomenon, and accounts for a growing quantity of power, exceeding 20 TWh in 2019. As the grid has evolved, adding both wind generation and transmission, it has returned to an operating point where 15% of wind power is curtailed or cleared at negative prices, and 25-30% is stranded power, using the average price of $5/MWh.

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1 INTRODUCTION

Facing the challenge of climate change, governments have put forward ambitious renewable standard portfolio (RPS) goals, which aims to reduce the carbon footprint of power production by increasing renewable generation[1, 6]. This drives the generation mix of power grids to shift rapidly towards renewable sources such as wind and solar. For example, in the region of the Electric Reliability Council of Texas (ERCOT), wind generation use (curtailment excluded) increased from 29.8 TWh to 76.8 TWh in 2012-2019, a compound annual growth rate (CAGR) of 14.5%. In 2019, wind generation accounts for one-fifth of energy use in ERCOT.

Table 1. ERCOT's Energy Use in 2012-2019 (Source: ERCOT Quick Facts)

Year	2012	2013	2014	2015	2016	2017	2018	2019
Energy Use (TWh)	324	331	340	347	351	357	376	384
Wind Generation Use (TWh)	29.8	32.7	36.1	40.8	53.1	62.2	69.8	76.8
Percentage	9.2%	9.9%	10.6%	11.7%	15.1%	17.4%	18.6%	20.0%

The growth of variable renewable generation also brings challenges to the power grids. Renewable generation can be curtailed due to congestion or excess generation [8]. Although economic

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dispatch can mitigate this problem by providing economic incentives and disincentives to generation, it results in uneconomic power, which is power sold at negative price. We use the term "stranded power" to describe both the curtailed and uneconomic power[1]. The stranded power in the Midcontinent Independent System Operator (MISO) and California Independent System Operator (CAISO) has been characterized in prior work[2, 3]. This study reports preliminary results of a similar analysis for the ERCOT power grid from 2012 to 2019. Insights include:

- Stranded power in the ERCOT grid is a persistent phenomenon, and accounts for a growing quantity of power, exceeding 20 TWh in 2019.
- As the grid has evolved, adding both wind generation and transmission, it has returned to an operating point where 15% of wind power is curtailed or cleared at negative prices, and 25-30% is stranded power, using the average price of \$5/MWh.
- Specifically, the quantity of stranded power was 28% of the total ERCOT wind generation in 2019.

2 DEFINITION OF STRANDED POWER

Following definitions in [2, 3], we define stranded power as two components: 1) *curtailment*, the power a generator would like to generate but cannot be transmitted into the grid; 2) *negative-priced power*, which is generated and transmitted into the grid but at a very low price. In particular, we focus on the stranded wind power in ERCOT.

2.1 Curtailment

The methodology of [2] computes curtailment as the difference between "Economic Max" and actual dispatched power in MISO's real-time cleared offers (RTO). Similarly, for ERCOT we define a generation resource's curtailment in an interval as the difference between high sustained limit (HSL) and dispatched power in MWs.

2.2 Negative-priced Power

ERCOT deploys security-constrained economic dispatch (SCED) to achieve power balance, congestion management, and least dispatch cost. Real-time local marginal prices (LMPs) are generated at each SCED cycle, about every 5 minutes. We use two methods to estimate the negative-priced power similar to [2].

Instantaneous Stranded Power is defined as the energy dispatched in 5-minute intervals in which LMPs are lower than a threshold C, and we call it $LMP(C)$. For generation resource i, the instantaneous stranded power is computed by:

$$LMP_i(C) = \sum_t MW_{i,t} \cdot \mathbb{1}(LMP_{i,t} \le C) \cdot \frac{1}{12}, \text{ (unit: MWh)}$$

Net Price Stranded Power is the total amount of energy dispatched in contiguous 5-minute intervals where the average LMP is lower than a threshold C. We call this $NP(C)$, which is formally defined as:

$$NP_i(C) = \sum_{period} MWh_{i,period} \text{ (unit: MWh)}$$

$$\text{where } \frac{\sum_{t \in period} LMP_{i,t} \cdot MW_{i,t}}{\sum_{t \in period} MW_{i,t}} \le C, \ \forall period$$

[1] In another study [3], uneconomic power was termed "opportunity power".

3 RESULTS

3.1 Setup

To characterize stranded wind power in ERCOT, we analyze operational details (real-time cleared offers) and LMP reports, which are described in Table 2. Each generation resource's type and settlement point are retrieved from ERCOT's 60-day generation resource data. We store the LMP entries in MongoDB, and match the cleared offers and LMPs by "BATCH_ID" and settlement point name.

Table 2. ERCOT Operational Details and LMP Data

Parameter	Value
Period	1/1/2013—12/31/2019
Generation Resources	769 Total, 251 Wind (as of 2019)

Column Name	Description
BATCH_ID	Unique numerical identifier of SCED cycle
SCED_TIMESTAMP	Start time of the 5-minute interval
LIMIT_HSL	Generation limit offered by generation resource
MW	Dispatched power in the interval
STLPNT_NAME	Connected settlement point
LMP	Local marginal price for the interval

To compute $LMP(C)$ of the whole grid, we simply sum up the dispatched energy in the intervals where $LMP \leq C$. For $NP(C)$, we use the algorithm below to compute the total amount and count the periods, which is an online algorithm that determines whether to append current 5-minute interval to the previous period.

Algorithm 1 Compute $NP(C)$ of a Generation Resource

Input: a generation resource i's cleared offers O, price threshold C
Output: $NP_i(C)$, periods P

$NP_i(C), np = 0$
$P, p = \phi$
for each $o \in O$ **do**
  Query LMP at time t from the database
  if averagePrice($p \cup t$) $\leq C$ **then**
    $p = p \cup t$
    $np = np + MW_t \cdot (1/12)$
  else
    $P = P \cup p, NP_i(C) = NP_i(C) + np$
    $p = \phi, np = 0$
  end if
end for
return $NP_i(C), P$

3.2 Year-to-year Changes

We select $LMP(0)$ and $NP(5)$ to show the trends as a conservative and a more aggressive estimate of stranded power. In both cases, we add the power curtailment to calculate the total stranded power. (Figure 1, Appendix A Table 3)

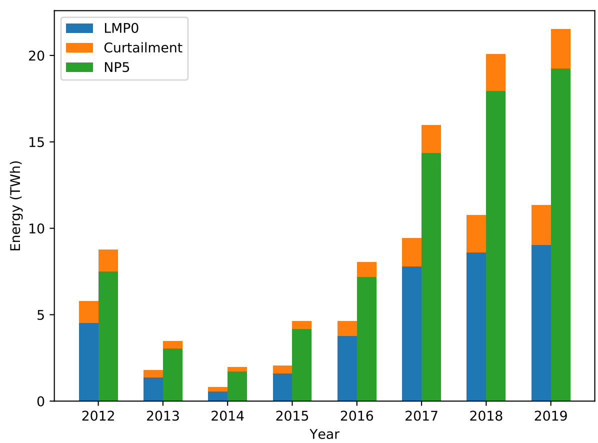

Fig. 1. Total Stranded Power in the ERCOT (LMP0 and NP5, 2012-2019)

As presented in Table 1, wind generation increased steadily each year from 2012 to 2019. However, analysis of stranded power exhibits a decrease in 2013 and 2014, and then returns to increases for five years, 2015-2019. In 2013 and 2014, the completion of the Competitive Renewable Energy Zone (CREZ) project, a transmission network, enabled more wind generation in West Texas to be sent across the state to large metropolitan load areas [7]. The addition of transmission mitigated congestion, allowing the growing wind power to be sold at higher prices, hence decreasing stranded power. However, as wind generation capacity continued to increase, the capacity of CREZ has become saturated, and stranded power has grown steadily, reaching more than 20 TWh in 2019.

As seen from the effects of transmission upgrades (CREZ), stranded power can be affected both by transmission as well as increasing wind generation. To examine the latter effect, we consider the ratio of stranded power to total wind generation. In Figure 2 (values in Appendix A Table 4), this ratio is plotted for 2012-2019, and shows a remarkably stable fraction for 2012, 2017, 2018, and 2019. This fraction is 15-20% for LMP0+curtailment and 25-30% for NP5+curtailment. It appears the CREZ impact on reduced congestion (2013-15) had largely been overtaken by wind generation growth by 2017, returning the grid to a high fraction of stranded wind power. That is by 2017, the ratio of stranded power under NP5 model with curtailment had nearly returned to its 2012 high of 30%. In recent years (2017-2019), with continued wind generation growth adding 23 TWh, the ratio has not changed much (≈15% for LMP0, ≈27% for NP5).

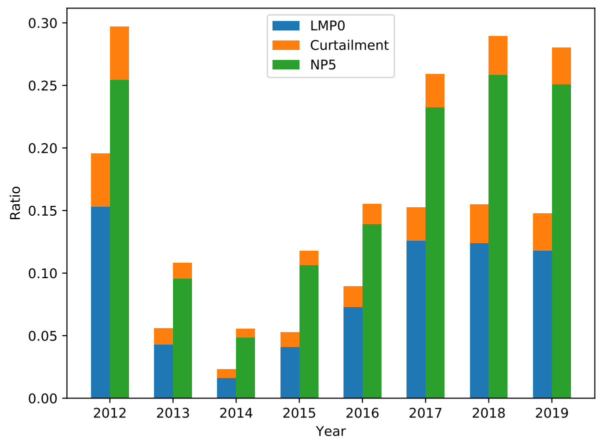

Fig. 2. Ratio of Stranded Power to Total Wind Generation (LMP0 and NP5, 2012-2019)

3.3 Seasonal Patterns

The seasonal distribution of wind generation for ERCOT is shown in Figure 3 (values in Appendix B Table 5). Because it is mainly determined by local climate and weather patterns, there is similar structure from year to year, with slightly lower production in Summer (June through August) and Autumn (September through November), an explanation of which can be found in [5].

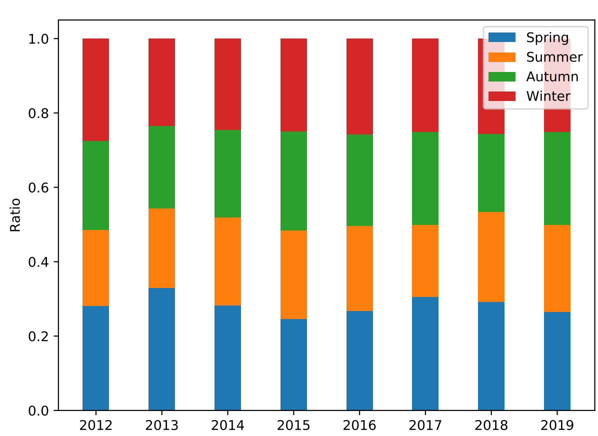

Fig. 3. Seasonal Distribution of Total Wind Generation (2012-2019)

The seasonal distribution of stranded power is shown in Figure 4 (values in Appendix B Table 6). It differs from wind generation, as it combines load with generation. In Summer and Autumn, there is higher power demand which combined with lower wind generation (supply) reduces stranded power significantly. As a result, the proportion of stranded power from Summer and Autumn contributes less to the annual total. Specifically, about 60%—80% stranded power arises in Winter (December through February) and Spring (March through May). Such seasonal variation is similar to that observed in other stranded power studies, but with different patterns due to differences in both seasonal weather (generation) and load [2, 3].

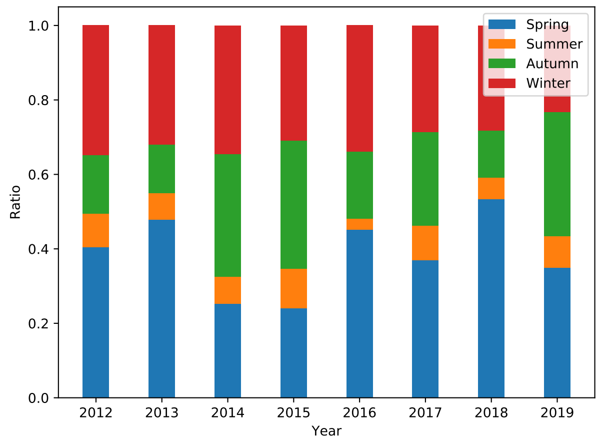

Fig. 4. Seasonal Distribution of Stranded Power (NP5 + curtailment, 2012-2019)

4 SUMMARY

In this report, we present a preliminary report on detailed study of stranded power in ERCOT with two models (LMP0 and NP5). These model estimate the quantity of low-cost power made available on an intermittent basis due to the variable generation of renewable sources. The results show that stranded power in the ERCOT grid is a persistent phenomenon, and accounts for a growing quantity of power, exceeding 20 TWh in 2019. As the grid has evolved, adding both wind generation and transmission, it has returned to an operating point where 15% of wind power is stranded (LMP0+curtailed) or as much as 25-30% is stranded power (NP5+curtailed). Specifically, the quantity of stranded power for NP5 was 28% of the total ERCOT wind generation in 2019. These results show that stranded power is increasing with the growth of wind generation in recent years. The year-to-year and seasonal pattern analysis imply that the amount of stranded power is related to many factors such as transmission constraints, grid load, and wind generation.

In future studies, its natural to consider other temporal and geographic characterizations of stranded power in ERCOT, such as what have been studied in [2]. And, an important question is how the stranded power can be put to use [4, 9, 10]. Together, these concerns may require detailed analysis of stranded power's spatial-temporal distribution, include the length of periods when stranded power arises.

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A YEAR-TO-YEAR TOTAL STRANDED POWER IN 2012-2019

Table 3 and 4 show the stranded power and corresponding ratios in 2012-2019, which are numerical results of Figure 1 and 2.

Table 3. ERCOT's Stranded Power in 2012-2019 (Unit: TWh)

Year	2012	2013	2014	2015	2016	2017	2018	2019
Curtailment	1.26	0.41	0.24	0.46	0.85	1.64	2.14	2.29
LMP0	4.52	1.38	0.58	1.61	3.78	7.78	8.61	9.06
NP5	7.50	3.04	1.71	4.18	7.18	14.35	17.93	19.23

Table 4. Ratios of Stranded Power to Total Wind Generation in 2012-2019

Year	2012	2013	2014	2015	2016	2017	2018	2019
Curtailment	0.042	0.013	0.007	0.011	0.016	0.027	0.031	0.030
LMP0	0.153	0.043	0.016	0.041	0.073	0.126	0.124	0.118
NP5	0.254	0.095	0.049	0.106	0.139	0.232	0.258	0.251

B SEASONAL DISTRIBUTION OF WIND GENERATION AND STRANDED POWER IN 2012-2019

Table 5 and 6 show the seasonal distribution of ERCOT's total wind generation and stranded power in 2012-2019, which are numerical results of Figure 3 and 4.

Table 5. Seasonal Distribution (Ratios) of ERCOT's Total Wind Generation in 2012-2019

Year	2012	2013	2014	2015	2016	2017	2018	2019
Spring	0.281	0.329	0.282	0.246	0.268	0.306	0.292	0.266
Summer	0.204	0.214	0.237	0.239	0.228	0.193	0.242	0.233
Autumn	0.240	0.223	0.235	0.266	0.247	0.251	0.210	0.251
Winter	0.275	0.234	0.246	0.249	0.257	0.250	0.256	0.250

Table 6. Seasonal Distribution (Ratios) of ERCOT's Stranded Power in 2012-2019

Year	2012	2013	2014	2015	2016	2017	2018	2019
Spring	0.404	0.479	0.253	0.241	0.452	0.369	0.534	0.349
Summer	0.090	0.071	0.072	0.105	0.030	0.092	0.058	0.085
Autumn	0.157	0.130	0.330	0.344	0.179	0.252	0.127	0.333
Winter	0.348	0.320	0.345	0.309	0.339	0.286	0.282	0.233