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Benchmarking U.S. Small Wind Costs

With the Distributed Wind Taxonomy

September 2017

AC Orrell
EA Poehlman



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Prepared for
the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99352

Executive Summary

Small wind turbines (i.e., up through 100 kW) make up a large percentage of domestic distributed wind projects and U.S. manufacturers accounted for nearly all U.S. domestic small wind sales in 2016. Despite this market share, small wind struggles to be cost competitive with other distributed generation technologies. Where solar photovoltaic systems and large-scale wind turbines have made significant progress in reducing costs, small wind has not.

The objective of this report is to benchmark costs for small wind projects installed in the United States using a distributed wind taxonomy. Consequently, this report is a starting point to help expand the U.S. distributed wind market by informing potential areas for small wind cost-reduction opportunities and providing a benchmark to track future small wind cost-reduction progress.

To benchmark small wind costs, this report uses a dataset with cost information from 70 projects using 10 turbine models in 16 states across the United States representing 1.5 MW in rated capacity. Projects are categorized as residential (those using turbines up through 20 kW) and commercial (those using turbines 21 kW to 100 kW). Residential systems account for 57 of the 70 projects; the remaining 13 are commercial systems.

Based on the collected cost data, a representative residential system has an average cost of \$11,953/kW and a representative commercial system has an average cost of \$7,389/kW.

Table ES.1 presents the breakdown of these costs, on both a cost per kW basis and a percentage of total system cost basis.

Table ES.1. Distributed Wind System Costs

Category	Residential (\$/kW)	Residential (%)	Commercial (\$/kW)	Commercial (%)
Wind turbine system equipment	4,410	37	4,393	59
Customer acquisition and qualification	144	1	51	1
Zoning, permitting, inspection, and incentives (ZPII) processing	791	7	274	4
Engineering and design	62	0	30	0
Transportation and logistics	225	2	130	2
Foundation	1,298	11	591	8
Electrical infrastructure	567	5	458	6
Installation	2,451	21	523	7
Taxes	139	1	40	1
Other costs	151	1	30	0
Overhead and profit	1,716	14	872	12
Total	11,953	100	7,389	100

The cost categories with the highest values, as percentages of the total distributed wind system costs on a per kW basis, are turbine system equipment (37% of total cost for residential systems, 59% of total cost for commercial systems), installation (21% residential, 7% commercial), overhead and profit (14% residential, 12% commercial) foundation (11% residential, 8% commercial), electrical infrastructure (5% residential, 6% commercial), and ZPII (7% residential, 4% commercial).

Cost reductions in these high-cost categories could significantly impact distributed wind system costs. However, this report is not a cost-reduction roadmap, nor does it address how susceptible each cost category is to cost-reduction. To move from this initial cost benchmark to identifying robust cost-reduction opportunities, additional data must be obtained to expand the dataset, cost models must be developed for certain cost categories, and the components of each cost category must be analyzed to determine what is driving the high costs and the high variances in some cost categories. Those actions will provide data-driven justifications for future cost-reduction actions.

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Acronyms and Abbreviations

BOS	Balance of Station
CIP	Competitiveness Improvement Project
DOE	U.S. Department of Energy
DWEA	Distributed Wind Energy Association
FAA	Federal Aviation Administration
ITC	investment tax credit
NREL	National Renewable Energy Laboratory
OEM	original equipment manufacturer
PNNL	Pacific Northwest National Laboratory
PV	photovoltaic
REAP	Rural Energy for America Program
SMART	Sustainable Manufacturing, Advanced Research & Technology
USDA	U.S. Department of Agriculture
WETO	Wind Energy Technology Office
ZPII	zoning, permitting, interconnection, and incentives

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1.0 Introduction

Distributed wind systems are installed at homes, businesses, farms, and industrial facilities to provide energy for local consumption. Consumers install distributed wind systems for a range of benefits—energy security, lower utility bills, a 20-year fixed energy rate, or to generate their own clean, renewable energy. Mirroring this variety of consumers and benefits is the wide range of distributed wind system installed costs. No two installations are identical and costs are variable.

Installers interviewed for this report and for the annual Distributed Wind Market Report repeatedly stated that the cost of distributed wind systems, especially when compared to solar photovoltaic (PV) systems, is the biggest barrier to increased adoption and sales.

The Pacific Northwest National Laboratory (PNNL) and National Renewable Energy Laboratory (NREL) team collected cost data to establish a benchmark for average distributed wind system costs for projects using small (up through 100 kW) wind turbines. Understanding costs is the starting point to identifying pathways to potential cost-reduction opportunities that can help increase distributed wind's competitiveness and expand the U.S. distributed wind market.

1.1 Background

In August 2014, the U.S. Department of Energy (DOE) Wind Energy Technology Office (WETO) issued a request for information to solicit feedback on the program's distributed wind strategic focus areas. Industry response indicated that in addition to next generation wind turbine technology development, understanding and reducing the non-hardware, or soft costs, of distributed wind was the highest priority for the industry.

The first step toward understanding all distributed wind costs was to create a classification system, or taxonomy, for distributed wind turbine installation and operation costs. A taxonomy allows for consistent categories and naming to evaluate costs and a structure to build a reliable dataset to establish a benchmark. The distributed wind cost taxonomy was published by NREL (Forsyth et al. 2017) and is summarized in Section 2.0 of this report.

With the taxonomy in place, the next step was to collect project cost data from project developers and installers to both test the taxonomy and build an initial dataset for the analysis presented in this report. Section 1.3 and Appendix A of this report describe the data-collection process.

In addition, NREL, on behalf of WETO, started the Distributed Wind Installers Collaborative to allow distributed wind installers, developers, and stakeholders to share knowledge and gain understanding of opportunities to increase domestic deployment and improve the U.S. distributed wind market. This collaborative is expanding access to and awareness of distributed wind technology and installation approaches with the goal of reducing risk and decreasing installation, development, and operational costs.

1.2 Report Focus

This report focuses on the costs associated with installed distributed wind projects that use new, behind-the-meter, grid-connected, small wind turbines (up through 100 kW) in the continental United States. While the data collection included distributed wind projects of all sizes, including some retrofit projects and a refurbished turbine model, to vet the taxonomy, the focus of this report is to set a benchmark for new small wind turbine project costs.

Large-scale, behind-the-meter distributed wind projects using turbines greater than 1 MW in size are not included in this analysis. Although large distributed wind projects may not benefit from the economies of scale that wind farms have, the types of costs incurred in large distributed wind projects can be more comparable to wind farms than to small wind projects. Distributed wind projects using mid-size turbines (101 kW to 1 MW) are limited in number in the United States, but the initial mid-size turbine data collected helped frame the taxonomy and validated that the taxonomy can address all distributed wind system sizes.

In 2016, 88% of documented distributed wind projects in the United States used small wind turbines and 98% of domestic small wind sales were from U.S. manufacturers. In addition, U.S. small wind turbine manufacturers have significant levels of exports each year. (Orrell et al. 2017). Despite this market share, small wind struggles to be cost competitive with other distributed generation technologies. Where solar PV and large-scale wind turbines have made significant progress in reducing costs, small wind has not.

Small wind projects using turbines from U.S. manufacturers make up a large percentage of the domestic distributed wind market, but they still have higher costs than other distributed generation technologies (i.e., solar PV). Focusing on small wind project costs to inform potential areas for cost-reduction opportunities and provide a benchmark to track small wind cost-reduction progress could significantly impact the U.S. distributed wind market.

The nominal, or nameplate, capacity of a wind turbine is what manufacturers use to describe, or name, their wind turbine models. A certified small wind turbine's rated capacity is its power output at 11 m/s per the American Wind Energy Association (AWEA) 9.1-2009 Standard. This report uses the total rated power capacity of the project in the cost per kW analyses. For turbines that are not certified, the power output at 11 m/s is assigned as the turbine's rated, or referenced, capacity, as shown in Section 3.0. In the long term, this approach could help differentiate costs between similar turbine models with different rotor diameters. Turbines with higher rated capacities typically have larger rotor diameters, so using rated capacity could help track the impact technology design can have on project costs.

1.3 Data-Collection Process

After the taxonomy was developed, the PNNL and NREL team worked with installers and developers to collect project cost data. The team collected two rounds of project data; the first in the spring of 2016 and the second in early 2017. The complete dataset includes 70 new small wind projects that were installed from 2012 to 2017 from 14 installers in 16 states for a total of 1.5 MW rated capacity.

The small wind dataset is informative, but has limitations. These limitations include a small sample size with an uneven geographic representation and lack of data in some cost categories. These issues may contribute to the large variances in some cost categories.

To be eligible to participate in the data collection, installers were required to have at least one distributed wind project with an installation date of 2012 or later; specific, itemized cost records for the project or projects; and the ability to provide that information within the requested timeline. These criteria limited the number of eligible installers. As a result, although the intent was to collect a representative sample of distributed wind projects from across the United States using a variety of turbine models, the initial dataset includes only a limited sample of projects.

Projects included in the dataset were installed throughout the year, not exclusively during any one season. Some projects may have higher costs because of winter construction issues; however, more than one

installer reported this potential issue, implying that winter installations are not atypical and therefore should not be excluded from average cost calculations.

As noted previously, installers reported a wide range of costs for most cost categories. Some reasons for these variances are noted with the analysis. However, a better understanding of the drivers of these variances is a necessary next step in comprehending distributed wind costs.

In addition, in some instances, installers were only able to provide limited information. For example, some provided a combined permitting cost, rather than a cost breakdown of the different project permits required; others provided only a combined turbine and tower cost; and others were not responsible for a certain aspect of the installation (e.g., the customer did the electrical work), so they could not report that cost. Consequently, sample sizes varied for each cost category based on available data. Figures included in this report note specific sample sizes using the number of projects and the corresponding combined rated capacity of the projects (e.g., 448.4 kW, 57 projects).

2.0 Taxonomy

As noted in Section 1.1, the first step toward understanding distributed wind costs was to create a classification system, or taxonomy. *The Distributed Wind Cost Taxonomy* (Forsyth et al. 2017) describes the structure rationale and development of that taxonomy.

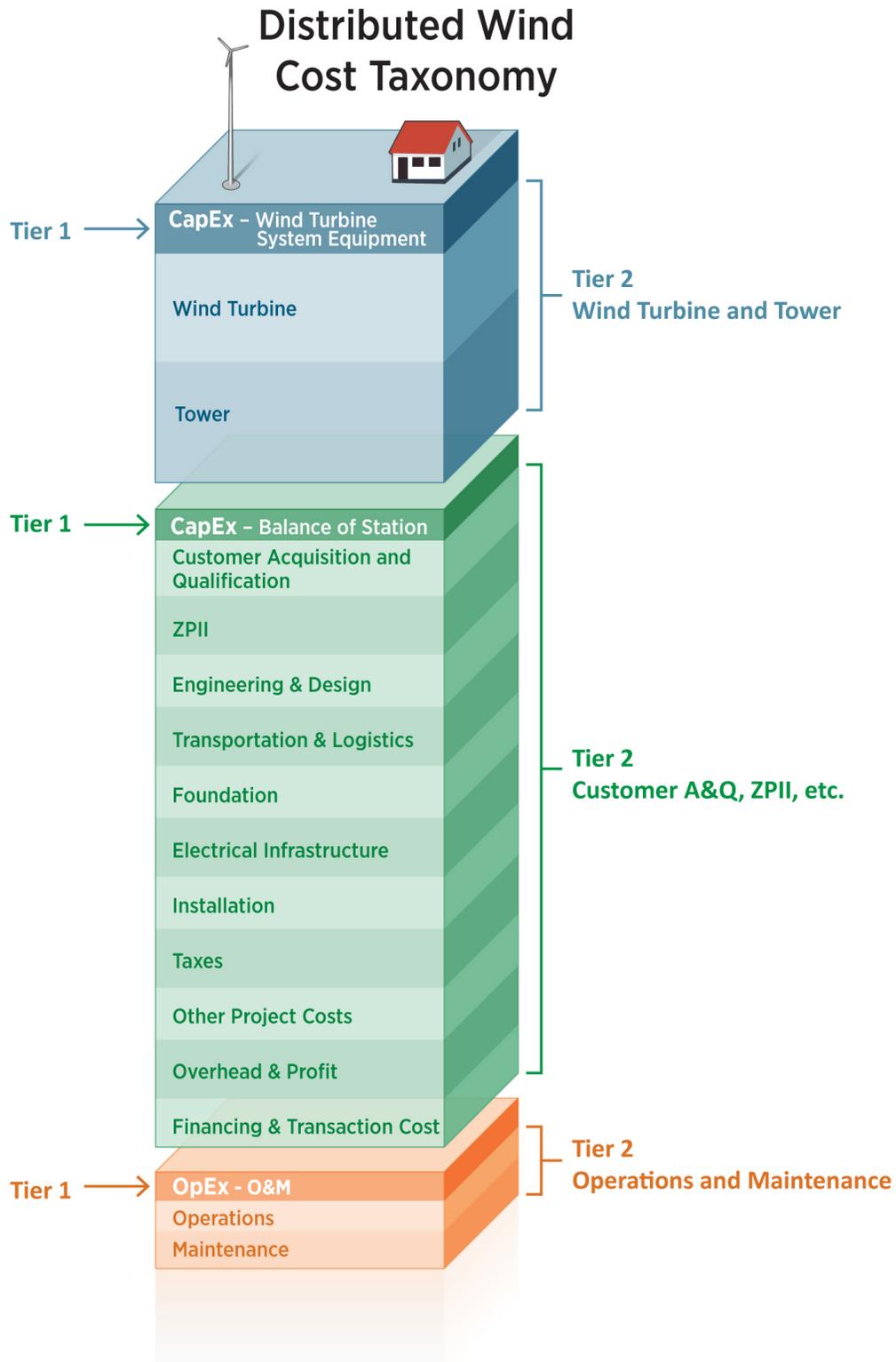
At its highest level, the distributed wind cost taxonomy is divided into the three Tier 1 categories shown in Figure 1. These include the following capital and operational expenditures:

- CapEx – Wind Turbine System Equipment
- CapEx – Balance of Station (BOS)
- OpEx – Operations and Maintenance.

Tier 1 categories can be subdivided into Tier 2 categories that are more granular (see Figure 1). Tier 2 items (e.g., installation) can be further divided into Tier 3 categories (e.g., installation includes site preparation and cleanup, commissioning, and other installation costs), which are not shown in Figure 1.¹

Forsyth et al. (2017) designed the taxonomy to be comprehensive, accounting for all costs for the purchase of the turbine equipment, installation and interconnection of that equipment, and maintenance of the wind turbine system over its operating lifetime, and to be applicable to all distributed wind projects and turbine sizes. As a result, distributed wind projects involving larger turbines may incur costs in categories that small wind projects do not experience. For example, some Tier 2 items (e.g., other project costs) and Tier 3 items (e.g., environmental permits in ZPII) may not be applicable to small wind projects.

¹ See Figure 3-3 of *The Distributed Wind Cost Taxonomy* (Forsyth et al. 2017) for an illustration of Tier 3 divisions.



Note: ZPII = zoning, permitting, interconnection, and incentives

Figure 1. Distributed Wind Cost Taxonomy (Forsyth et al. 2017)

3.0 Dataset Demographics

The team acquired cost data from 14 installers for 70 small wind projects installed from 2012 to 2017 using 10 turbine models² across the continental United States. Figure 2 shows the project breakdown by geographic region and Table 1 presents the turbine models included in the dataset.

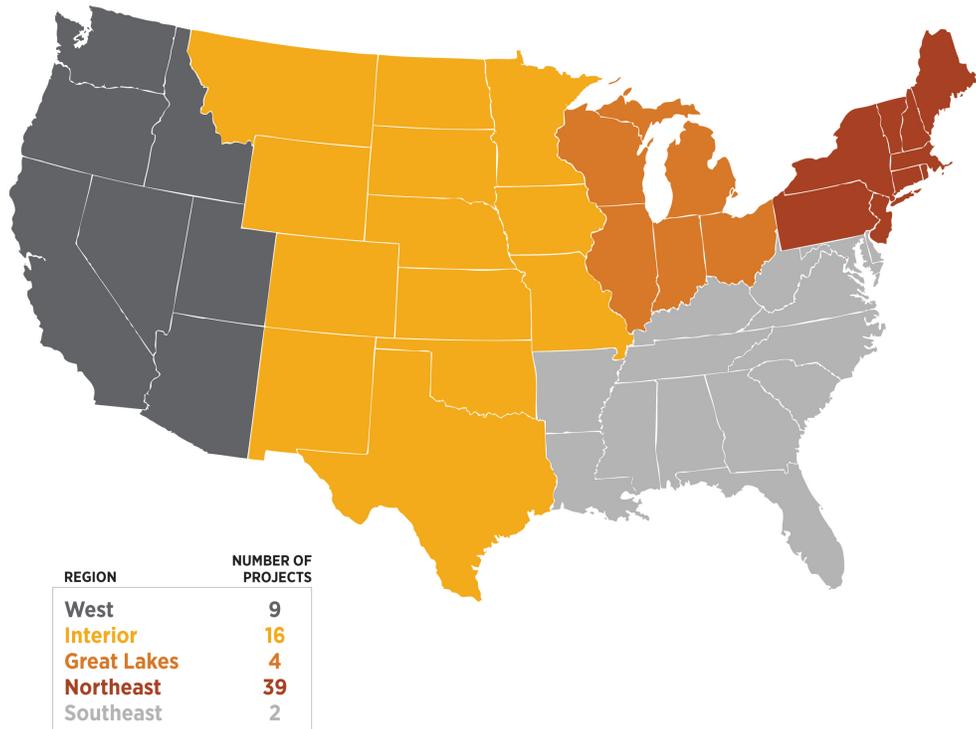


Figure 2. Project Breakdown by Region

In addition to Forsyth et al. (2017), cost benchmarking in this report relies on *Assessing the Future of Distributed Wind: Opportunities for Behind-the-Meter Projects* (Lantz et al. 2016) to classify small wind projects. In Lantz et al. (2016), small wind is divided into two turbine technology classes: residential (turbines up through 20 kW in size) and commercial (turbines from 21 to 100 kW). These labels refer specifically to the size of turbines, and not a customer or end-user category. While any size turbine may be used for any kind of end-use, this size classification presumes turbines up through 20 kW are more likely to be used behind the meter for homes and small farms (residential) and 21 to 100 kW turbines are more likely to be deployed at larger farms and small business operations (commercial). This report divides the collected project data into these two size classifications—residential and commercial—for analysis. Of the 70 small wind projects, 57 are residential systems and 13 are commercial systems.

The 14 different installers represent 13 independently operated companies and one leasing company. Small company installers are paid by their customers for the turbine installation and, thus, their customers own the completed project. Leasing companies provide a lease arrangement that allows their customers to

² Two NPS 100 models, one with a rotor diameter of 21 m and a next generation model with a rotor diameter of 24 m, are counted as different turbine models.

lease a wind turbine system that is installed and owned by the leasing company, but installed on the customer’s property. Customers make monthly payments in exchange for the installation, operation, and maintenance of the wind turbine system, and the energy produced by the onsite turbine displaces the customer’s electricity consumption from the utility with the intent of lowering their utility bills.

A few projects used more than one turbine. This report uses the total rated, or referenced, power capacity of the project in the cost per kW analyses.

Table 1. Turbine Models in Small Wind Dataset

Turbine Models	Size Classification	Rated or Referenced Power at 11 m/s	Nominal Turbine Capacity (kW)	Number of Projects	Number of Turbines
Bergey Excel 10	Residential	8.9 ^(a)	10	42	42
Dakota Turbines DT-30	Commercial	25 ^(b)	30	2	2
Endurance E-3120	Commercial	56 ^(c)	50	6	9
Endurance S-343	Residential	5.4 ^(d)	5	1	1
NPS 100-21	Commercial	79 ^(e)	100	1	1
NPS 100-24	Commercial	90 ^(b)	100	4	5
Osiris 10	Residential	9.8 ^(a)	10	1	1
Pika T701	Residential	1.5 ^(a)	1.7	2	2
Southwest Windpower / Xzeres Skystream 3.7	Residential	2.1 ^(a)	2.4	8	12
Xzeres 442SR	Residential	10.4 ^(a)	10	3	3
			Total	70	78

(a) Small Wind Certification Council (SWCC) full certification to AWEA 9.1-2009 Standard.

(b) Manufacturer’s power curve.

(c) SWCC power performance certification to IEC 61400-12-1.

(d) SWCC limited power performance certification to AWEA 9.1-2009 Standard.

(e) DNV power performance certification to IEC 61400-12-1.

4.0 Costs Analysis

Using the distributed wind cost taxonomy as a guide, the focus of the analysis in the following sections is on Tier 1 and Tier 2 cost categories. When warranted (i.e., sufficient data are available), Tier 3 cost categories are also examined to help explain Tier 2 costs. All costs are in 2016 dollars.

4.1 Wind Turbine System Equipment and Balance of Station

Figure 3 provides the costs for two Tier 1 categories (i.e., wind turbine system equipment and BOS).³ Wind turbine system equipment costs are the wind turbine and tower costs. The wind turbine cost may include optional turbine system equipment (e.g., anemometer monitoring equipment) and the cost of a turbine manufacturer’s extended warranty. In addition, Figure 3 breaks out the Tier 2 costs for the BOS category.⁴

³ If a cost was not reported for a given project, that specific cost was excluded from the average in Figure 3, and subsequent figures, rather than excluding the whole project.

⁴ Financing and transaction costs are excluded as explained in Section 4.3.11.

Based on the dataset, a representative residential distributed wind system has an average cost of \$11,953/kW and a representative commercial distributed wind system has an average cost of \$7,389/kW.⁵

Figure 4 provides the same total cost overview, but with the wind turbine system equipment and BOS costs presented as percentages of the total system cost. Wind turbine system equipment and BOS costs are examined in detail in Sections 4.2 and 4.3, respectively.

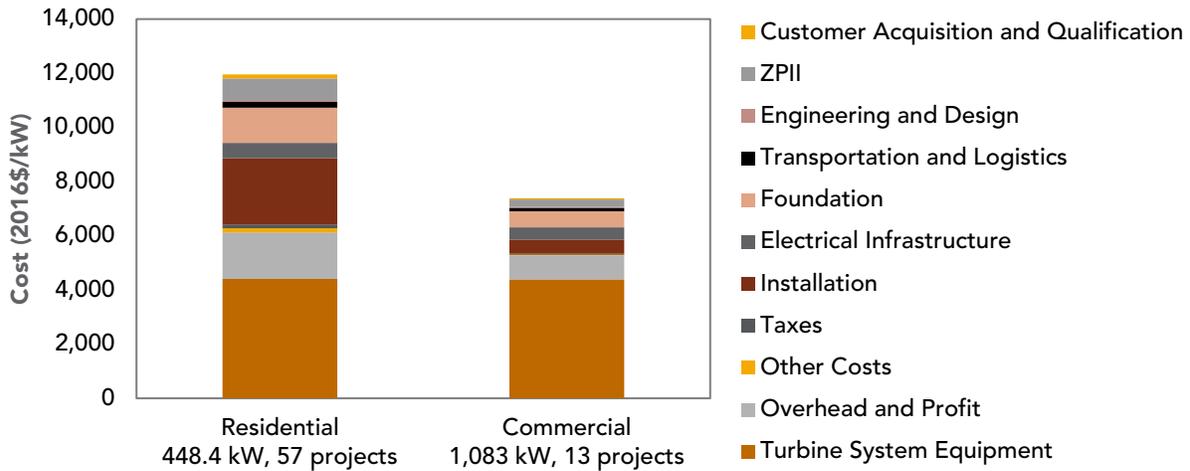


Figure 3. Wind Turbine System Equipment and Balance of Station Costs on a per kW Basis

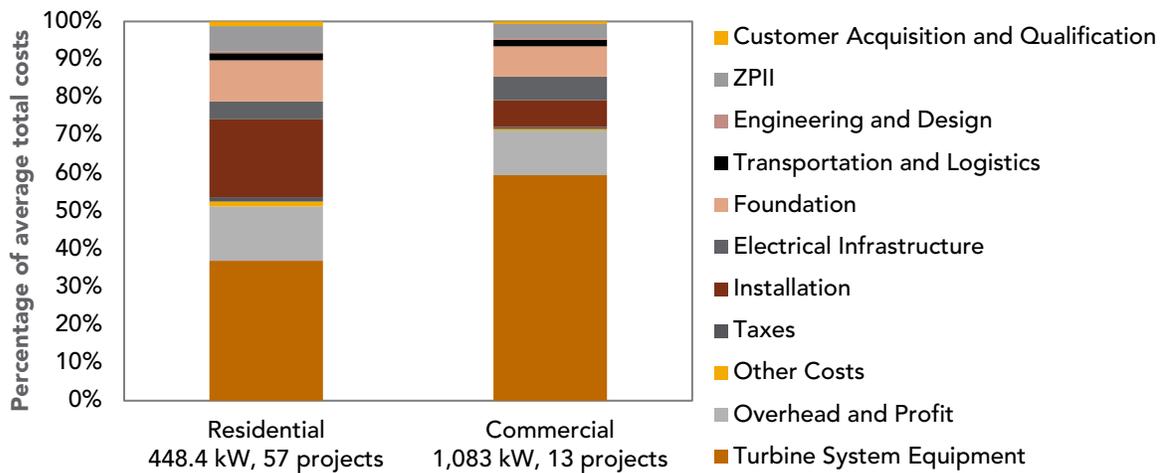


Figure 4. Wind Turbine System Equipment and Balance of Station Costs on a Percentage Basis

⁵ These average costs are higher than the average costs reported in the 2016 Distributed Wind Market Report. For this report, installers were asked to provide itemized labor, material, and equipment costs for ALL the parts of a project, even parts that may not have been invoiced to the customer (e.g., shipping costs the installer had to absorb because of a delay from the turbine manufacturer or labor time spent attending a zoning meeting with a customer). For the Market Report, installers typically report just the invoice price to the customer and small wind turbine manufacturers report generic, average installed costs.

4.2 Wind Turbine System Equipment

The Tier 1 Wind Turbine System Equipment category is comprised of two Tier 2 categories: wind turbine costs and tower costs. The wind turbine cost may include optional turbine system equipment (e.g., anemometer monitoring equipment) and the cost of a turbine manufacturer’s extended warranty. Figure 3 reflects the wind turbine system equipment cost to the installer. In most cases, the installer applies a markup to the wind turbine and/or tower prices from the respective manufacturers that is passed on to the customer. In that case, that markup, along with any other markups, are accounted for in the overhead and profit value discussed in Section 4.3.10.

While the residential and commercial systems have roughly the same average wind turbine system equipment cost, \$4,410/kW and \$4,393/kW, respectively, wind turbine system equipment accounts for 37% of the total average residential project cost and 59% of the total average commercial project cost. Average residential wind turbine costs are \$2,967/kW and average tower costs are \$1,443/kW. Average commercial wind turbine costs are \$3,517/kW and average tower costs are \$876/kW.

Typically, larger turbines are expected to have lower costs per kW than smaller turbines, but this is not the case for this dataset. More data and analysis are needed to understand if this difference is because of the commercial sample size (i.e., 13 projects from seven installers using turbines from three manufacturers) or for other reasons.

Taking a closer look at towers, Figure 5 presents the average and project-specific residential and commercial tower costs by tower type using the metric of cost per kW per meter of tower height. In general, the taller the tower, the higher the cost. The high residential monopole tower costs, those over \$100/kW/m, are all for small wind turbines 2.5 kW in size or smaller. Of the 66 projects included in Figure 5, 46 used freestanding lattice towers, 19 used freestanding monopole towers, and 1 used a guyed lattice tower.

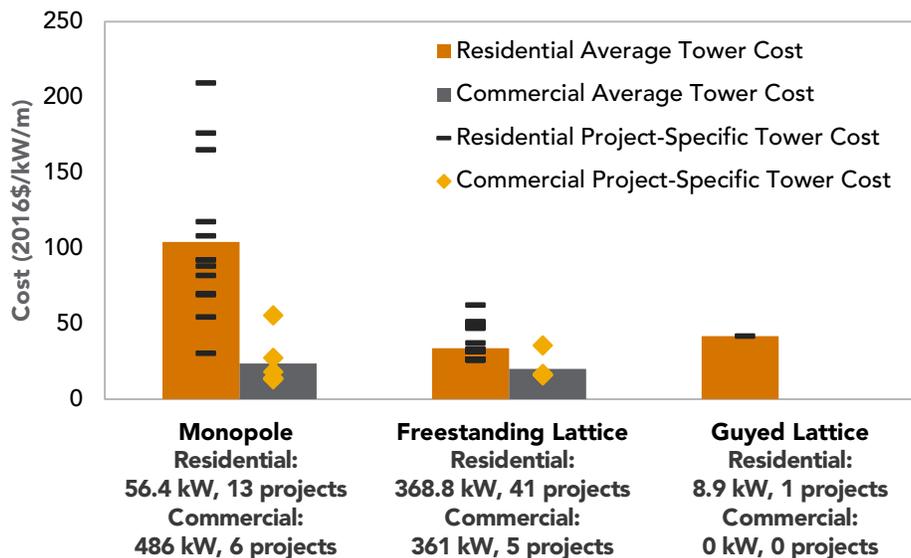


Figure 5. Average and Project-Specific Tower Costs by Tower Type

4.3 Balance of Station

BOS costs include all costs for an installed wind turbine system other than the wind turbine system equipment discussed in Section 4.2. The distributed wind industry uses a large range of turbine sizes, resulting in significant differences in equipment requirements, engineering studies, access issues, site-preparation protocols, and other factors. The BOS Tier 2 and Tier 3 taxonomy categories were developed to account for this wide variety of deployments. Each BOS Tier 2 category reflects the sum of its Tier 3 costs (e.g., engineering studies for engineering and design). The team asked installers and developers to provide further detail of the Tier 3 cost categories by providing, when available, what would be considered Tier 4 categories—labor, equipment, and material costs.

4.3.1 Customer Acquisition and Qualification

Customer acquisition and qualification activities include marketing and advertising and conducting site and wind resource assessments. The customer acquisition and qualification cost averages of \$144/kW for residential and \$51/kW for commercial shown in Figure 3 are site and wind resource assessment costs. Marketing and advertising costs are not typically associated with specific projects and are, therefore, considered part of the overhead costs discussed in Section 4.3.10.

Wind resource assessment costs were not incurred for most residential projects (i.e., only 4 assessments in 57 projects); however, the numbers were higher for commercial projects (i.e., 5 assessments in 13 projects).⁶ Installers did not incur these costs for a variety of reasons. In one case, the turbine was installed for educational purposes, so a wind resource assessment to estimate energy production was deemed unnecessary. In other cases, the customer did not request an assessment or costs were minimal, and therefore not tracked, because the installer used the turbine manufacturer’s website tool to estimate an energy-production value or the manufacturer provided an estimate.

To qualify customers, companies conduct phone interviews, review site photos, and use online tools, such as Google Earth, to evaluate a site and provide a rough cost estimate. If a customer is still interested after this initial discussion, a company representative typically visits the customer’s site and prepares a formal proposal. Most installers reported a cost for this typical site-assessment process. Excluding travel time, time spent evaluating the site and wind resource and closing the deal ranged from 3 to 5 hours. If significant travel is required for a site visit, the overall process is longer because a site visit can take a full day.

Phone interviews and desktop assessments are important steps in the site-assessment process because they separate interested customers from others who are, in the words of one installer, “just kicking the tires.” Some installers noted that because their potential customers are spread out over a large area (i.e., western and midwestern states), the qualification process is critical in minimizing travel and site-visit expenses that do not result in sales.

4.3.2 Zoning, Permitting, Interconnection, and Incentives Processing

Costs associated with ZPII include fees and labor costs associated with obtaining the appropriate zoning approval, permits, and interconnection agreements and processing the required forms for local, state, and federal incentives. The taxonomy also accounts for the time (both processing and calendar time) required to pursue and obtain regulatory and utility approvals. Some installers do not include the cost of their labor

⁶ This excludes the leasing company that did not provide wind resource assessment break out costs, but does have a process for assessing wind resources and estimating energy production values for its customers.

for pursuing ZPII approvals in their customer invoices, instead seeing it as part of overhead or customer service. Alternatively, some ZPII costs are paid directly by the customer and are, thus, not costs incurred by the installer.

As shown in Figure 6, the total ZPII cost average for residential systems is \$791/kW and \$274/kW for commercial systems, or, as shown in Figure 7, 7% of total cost for residential systems and 4% of total cost for commercial systems. For projects that provided itemized ZPII costs, Figure 6 shows the breakdown of these ZPII costs on a dollar per kW basis. (The subset of residential projects in Figure 6 has a lower average ZPII cost than the full residential dataset included in Figure 3 because most of the residential projects that did not provide a breakdown of ZPII costs had higher overall ZPII costs.) Figure 7 shows the individual ZPII costs as percentages of the overall total ZPII cost.

Similar to other BOS costs, the dataset includes a wide range of reported ZPII costs, from \$56/kW to \$1,983/kW with no strong patterns. Turbine size obviously has an impact on the cost per kW metric. For example, the project with the highest total ZPII dollar value was a 100 kW commercial project, allowing for a lower cost per kW than some smaller projects in the dataset who also had high ZPII costs. The project with the highest total ZPII dollar value was in an urban location which had extensive permitting requirements. In contrast, a project on a farm was exempt from permitting requirements because it was sited on agricultural property, but drawing conclusions without more data is not recommended at this point.

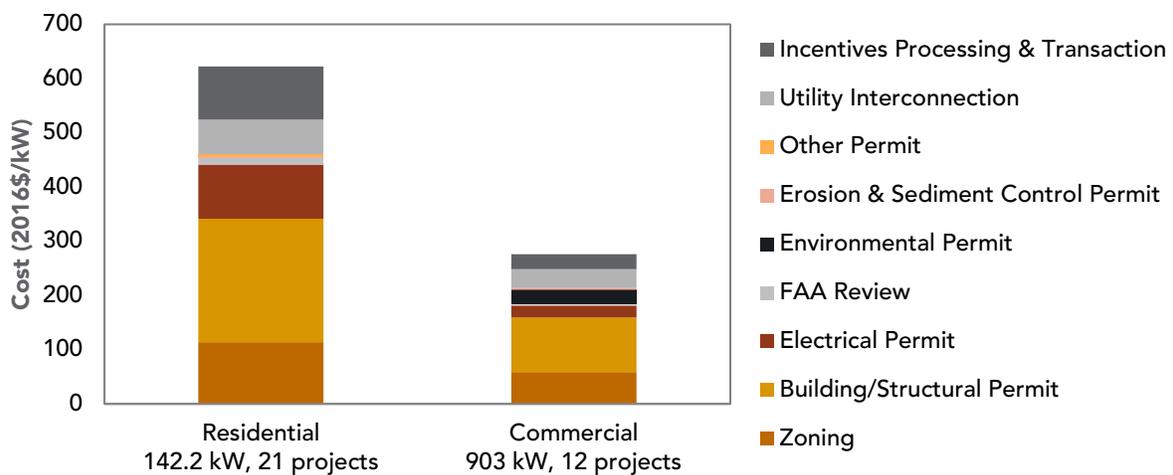


Figure 6. ZPII Costs Breakdown on a Cost per kW Basis

4.3.2.1 Zoning

Zoning ordinances define the rules or regulations that local governments apply to buildings or structures on private land. Some jurisdictions have zoning ordinances that specifically cover small wind, but most do not. Individual wind turbine systems typically fall outside standard community zoning ordinances. This means that sometimes the first cost a project incurs is obtaining approval for a zoning variance.

Zoning costs include all costs associated with applying, developing the appropriate documentation, and working through the zoning process. As shown in Figure 6, zoning represents 18% and 21% of the total ZPII cost for the residential and commercial systems, respectively. The 18% value is of total ZPII cost, which for residential systems is 7% of total system cost. Therefore, zoning represents round 1% of the total cost for residential systems, based on the successfully installed projects in the dataset. However, if a project fails because a zoning variance is not obtained, that cost is not tracked within the taxonomy because the system was not installed.

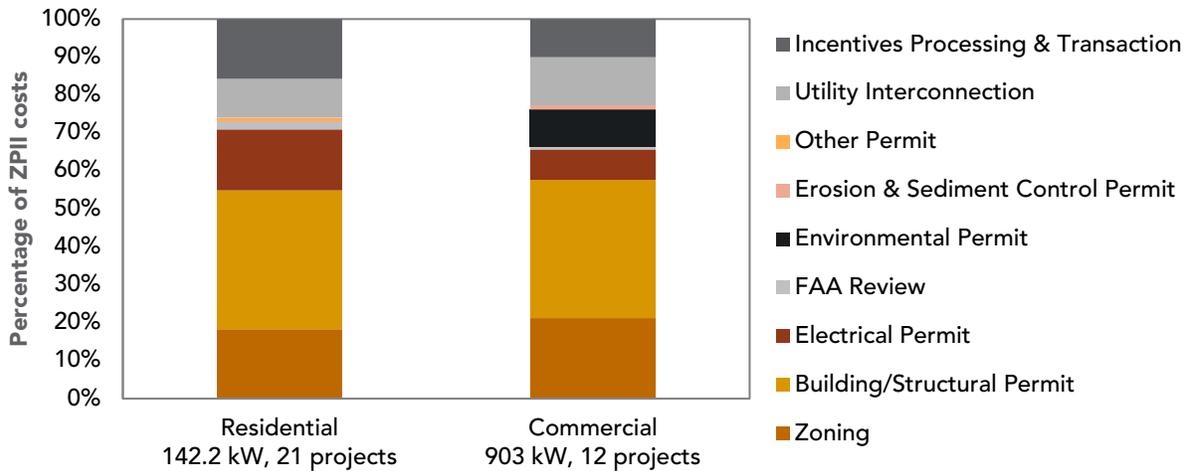


Figure 7. ZPII Costs Breakdown on a Percentage Basis

Dissected zoning costs were only captured for a small number of projects because some installers were only able to provide one combined ZPII cost and others were not directly responsible for obtaining the zoning approval, so could not report a cost. More zoning data are needed to draw any conclusions regarding zoning costs. For example, one project on tribal land incurred extensive zoning costs while another, on different tribal land, had no zoning costs.

4.3.2.2 Permitting

The primary permits for distributed wind systems are building/structural, electrical, Federal Aviation Administration (FAA) review and approval,⁷ environmental, and erosion and sediment control. The taxonomy also includes an “other permit” category to capture any non-typical permits. Building/structural permits account for the majority of the permitting costs, representing 37% and 36% of the total ZPII costs for residential and commercial systems, respectively. Electrical permits represent 16% and 8% of the total ZPII costs for residential and commercial systems, respectively.

Building/structural permit costs make up the largest percentage of the total ZPII costs because those costs include foundation design and geotechnical reports. For projects that incurred foundation design and geotechnical report costs, these costs accounted for 25% to 100% of the building/structural permit cost. When the taxonomy was developed, Forsyth et al. (2017) concluded that these types of engineering tasks could arguably go under engineering and design or ZPII, given that they are often conducted as part of the permitting process. Ultimately, these costs were placed within ZPII to better characterize the aggregate regulatory burden.

The taxonomy is comprehensive to account for all types and sizes of distributed wind projects; however, some cost items are not universal. No residential projects required environmental permits and only two projects (one residential and one commercial) required an erosion and sediment control permit. Similarly, permitting and zoning are primarily done at the local level (i.e., county or town and sometimes state), with the exception being FAA review and approval when required. Only 3 of the 21 residential projects, and 8 out of 12 of the commercial projects, included in Figure 6 had FAA review and approval costs.

⁷ FAA review and approval is only required for wind turbines near airports and/or more than 200 feet in height above ground level.

4.3.2.3 Interconnection

Connection of a distributed wind system to the utility grid requires an approved interconnection agreement. For residential and commercial size systems, this is usually a simple standard contract provided by the local utility. Only 3 of 21 residential projects and 3 of 12 commercial projects had long (i.e., five pages or more) utility interconnection form—as opposed to a shorter form (i.e., four pages or less). Projects with long forms generally reported higher utility interconnection costs. Utility interconnection costs represent 10% of total ZPII costs for residential systems and 13% for commercial systems.

4.3.2.4 Incentive Processing and Transaction

Distributed wind projects can take advantage of a combination of local, state, federal, and utility-based incentives. These incentives typically require application paperwork and sometimes application fees to the incentive program or to a grant writer, who is paid to complete an application on the customer's behalf. Incentives processing and transaction costs represent 16% of total ZPII costs for residential systems and 10% for commercial systems. A total of 12 out of 21 residential projects and 6 out of 12 commercial projects included in Figure 6 had some incentives processing and transaction costs.

State incentives reported include California's Emerging Renewables Program (which is no longer available), the New York State Energy Research and Development Authority's Small Wind Turbine Incentive Program, support from the Massachusetts Clean Energy Center, and the Energy Trust of Oregon's Small Wind Incentive Program. Federal incentives reported include the Business Energy Investment Tax Credit (ITC) and Residential Energy Tax Credit,⁸ Section 1603 cash payments, U.S. Department of Agriculture (USDA) Rural Energy for America Program (REAP) grants, and Modified Accelerated Cost Recovery System depreciation. The single utility-based incentive reported was from Pacific Power's Blue Sky program, available in California, Oregon, and Washington.

Customers are not guaranteed cash-based incentives from state and federal program. Therefore, some installers reported hiring grant writers to improve their customers' USDA REAP grant applications. In addition, acquiring an incentive from a program that requires a meter and detailed paperwork can generate additional labor costs and fees. Simplifying incentive requirements and applications may lower incentive processing and transaction costs; however, cost-reduction measures must not compromise programs' abilities to fund quality distributed wind projects.

4.3.3 Engineering and Design

Engineering and design costs are engineering studies and inspection and testing not related to site assessments or zoning or permitting requirements. Foundation engineering and design costs are included with the building/structural permit. Very few projects had engineering studies and inspection and testing costs, and those that did had low costs. As a result, engineering and design costs are less than 1% of total cost for both average residential and average commercial distributed wind systems. Larger projects have higher engineering and design costs because they typically require a more in-depth engineering analysis whereas many small wind turbine manufacturers can provide generic engineering studies that can be applied to multiple projects.

⁸ It is assumed that eligible customers with grid-connected distributed wind systems took advantage of the federal Business Energy ITC or Residential Energy Tax Credit, even when not reported or aided by the installer. Average costs in this analysis are not reduced by the value of these tax credits or any of the incentives received.

4.3.4 Transportation and Logistics

Transportation and logistics costs are the costs to ship the turbine to the customer site from the turbine manufacturer (e.g., by truck or rail). If the turbine cannot be shipped directly to the customer site, temporary warehousing or other delivery costs may be incurred. Residential projects have an average transportation and logistics cost of \$225/kW, and exhibit a wide cost range compared to commercial projects, with an average transportation and logistics cost of \$130/kW, as shown in Figure 8; however, residential and commercial costs each represent 2% of total project cost on average.

The wide range in costs for residential systems can be attributed to the various shipping and delivery methods and starting points reported by the installers. One installer lowered his shipping costs by having a bulk purchase of five turbines shipped to his warehouse by a shipping contractor rather than having the turbines shipped individually to each site by the turbine manufacturer. For some other projects, turbines and towers were shipped to the customer site separately from their respective manufacturers in different locations. Not all installers reported how or from where equipment was shipped or separate shipping costs for the tower and turbine, if applicable. Therefore, more detailed data are needed to understand these costs and whether they present cost-reduction opportunities.

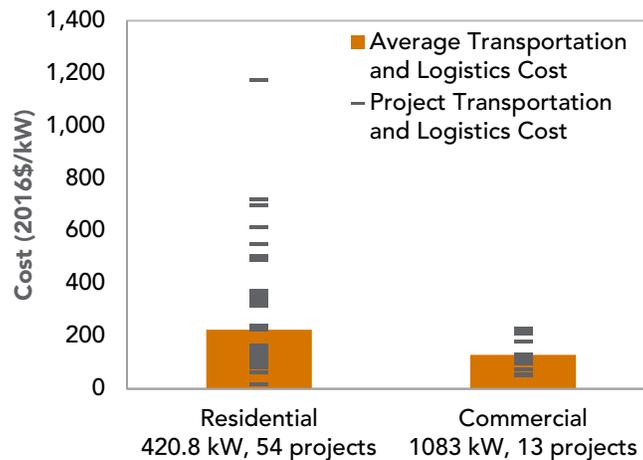


Figure 8. Average and Project-Specific Transportation and Logistics Costs

4.3.5 Foundation

Foundation costs are the labor, equipment, materials, and subcontract costs required to install a foundation. Figure 9 shows the averages of \$1,298/kW for residential and \$591/kW for commercial systems and the range of reported project-specific foundation costs, or 11% of the average total cost for residential systems and 8% for commercial systems as shown in Figure 4.

Although Figure 9 presents average foundation costs on a per kW basis, this report cannot provide clear conclusions about foundation costs with the limited sample size and no engineering analysis of foundation types and costs. Foundations types cannot be compared across a range of turbine sizes without correcting for the size impact on costs. For example, pier and pad foundations are generally less expensive than slab foundations. However; the per kW foundation cost for a larger turbine is still less for any type of foundation. Tower height, tower type, and geotechnical conditions (i.e., soil types) also impact foundation cost. In addition, a pier and pad foundation can have one pier for a monopole tower or three or four piers for a lattice tower. Although both are still pier and pad foundations, they are not comparable.

Because of these issues, more analysis, such as the development of a cost model, is needed to understand foundation costs and cost averages.

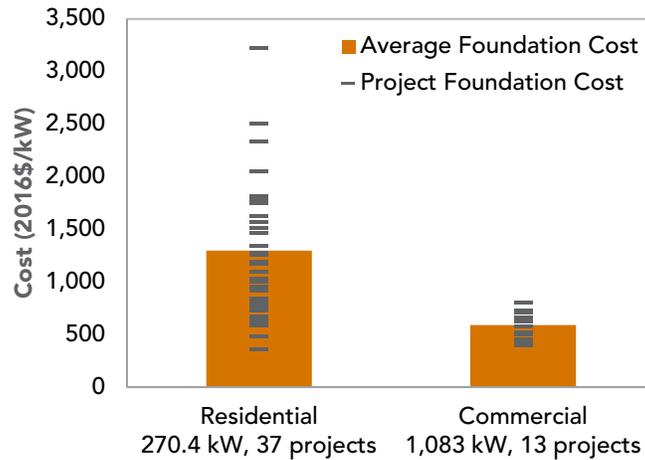


Figure 9. Average and Project-Specific Foundation Costs

4.3.6 Electrical Infrastructure

Electrical infrastructure costs include the labor, equipment, materials, and subcontract costs required to wire the turbine generator through any external controls and power conditioning equipment to the utility interconnection or onsite power distribution system. Figure 10 shows the averages of \$567/kW for residential and \$458/kW for commercial systems and the range of reported project-specific electrical costs. These costs are about 5% of total cost for residential systems and 6% for commercial systems. The two high residential electrical costs, those above \$1,000/kW, are each for a small wind turbine (10 kW in size or smaller). More analysis on what drives electrical costs, especially for the high residential costs in this dataset, is needed.

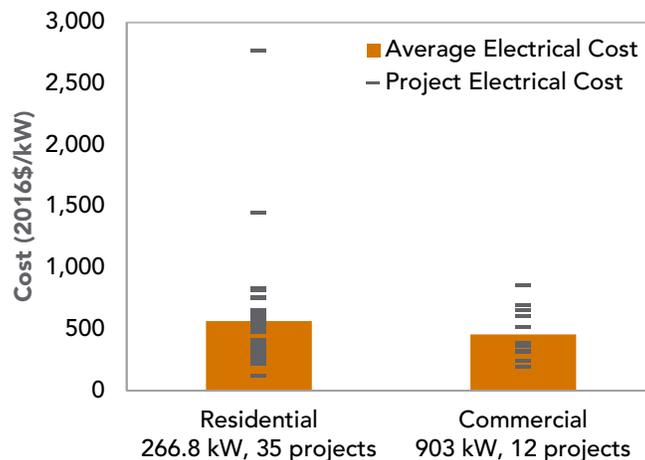


Figure 10. Average and Project-Specific Electrical Infrastructure Costs

4.3.7 Installation

Installation costs include labor, equipment, and materials costs for site preparation and cleanup, turbine and tower installation, commissioning, and all other construction-related costs.

Figure 11 shows the average installation cost of \$2,451/kW for residential systems and \$523/kW for commercial systems and the range of project-specific installation costs for both the residential and commercial class sizes. At the low end of the residential installation cost range, some projects had minimal installation costs because the system's tilt-up tower required very little labor and few tools.

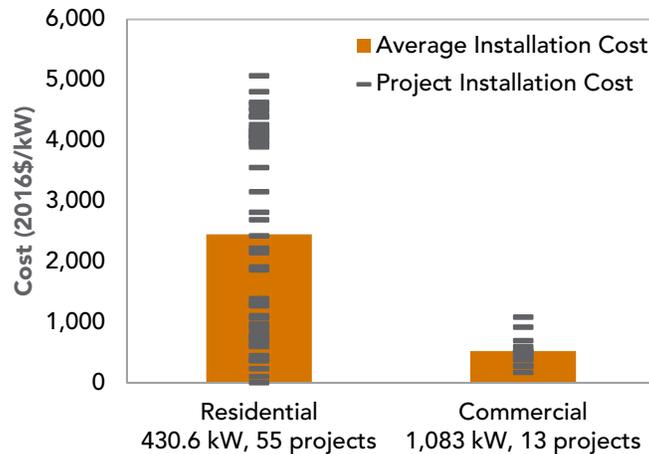


Figure 11. Average and Project-Specific Installation Costs

Installation costs represent 21% of the total average residential system cost and 7% of the total average commercial system cost. Typically costs roughly scale with turbine size (i.e., commercial costs per kW are generally half that of residential); however, many residential projects in the dataset had high turbine and tower installation costs, creating an apparent discrepancy between the residential and commercial installation cost averages. A detailed look at the lower-tier installation costs (i.e., labor, crane, and material) is needed to understand this discrepancy. For example, freestanding lattice is the dominate tower type for residential systems, as shown in Figure 5. As also shown in Figure 5, lattice tower equipment is typically less expensive than monopole tower equipment; however, lattice towers can be more expensive to install.

4.3.8 Taxes

The average taxes paid, \$139/kW for residential systems and \$40/kW for commercial systems shown in Figure 3, are based on the projects that had itemized taxes or known sales tax exemptions. If a project incurred import taxes, that cost was included in the turbine cost from the manufacturer and not reported separately. Sales tax rates vary by state. Sales tax may have also been included in the total turbine cost from a manufacturer, and not reported separately. Sales tax exemptions, reductions, or credits for small wind systems are available in 16 states (i.e., Arizona, Colorado, Iowa, Indiana, Maryland, Massachusetts, Minnesota, Nebraska, New Mexico, Nevada, Rhode Island, Tennessee, Utah, Vermont, Washington, and Wisconsin), although local taxes may still apply. As a result, estimating taxes based on published tax rates and tax exemption incentive programs, rather than on relying on installer reports, is likely a more effective approach to understanding the impact taxes have on distributed wind costs.

4.3.9 Other Project Costs

Other project costs include any remaining costs that could not be easily assigned to specific cost categories. In general, these other costs could include allocated operating expenses and project-development, management, and construction-management costs. For the residential projects, the other costs reported were primarily allocated operating expenses. For the commercial projects, the other costs reported were development and project management costs. As shown in Figure 4, these other costs are small, just 1% for residential and less than 1% for commercial, but may be significant for larger distributed wind projects.

4.3.10 Overhead and Profit

Installers and developers were asked to report overhead and profit for their projects. In general, overhead and profit is the difference between the total cost to the installer and the invoice price to the customer. As noted previously, the overhead and profit value includes any markup the installer added to the wind turbine system equipment and any other markups applied to cover the installer's common business expenses. These expenses include office space, administrative labor, corporate management expenses, business operations, and marketing and advertising costs.

Marketing and advertising expenses occur for companies looking to grow or ensure their sales. Types of these expenses reported include printed materials (e.g., fliers and handouts); booth rentals at trade shows and fairs; website and magazine advertising; sales commission for customer leads; and hiring outside consultants. Several companies rely on referrals and word of mouth for customer acquisition, with one company noting that up to 75% of its sales come from word of mouth referrals and another stating that many of its customers are acquired through trade shows. Alternatively, some companies have all but ended their expenses for wind-specific marketing and customer acquisition due to low success rates in obtaining wind project customers. Therefore, reported marketing and advertising costs range from zero, to \$300 a year for a webpage, to \$10,000 a year to participate in trade shows and fairs and create printed advertisements.

Installers' costs from site assessments (part of customer acquisition and qualification) or from hitting ZPII barriers (i.e., zoning and permitting efforts for projects that were not ultimately installed) may also be absorbed as an overhead cost. Even for successful projects, as mentioned in Section 4.3.2, some installers do not include the cost of their labor for pursuing ZPII approvals in their customer invoices, instead seeing it as part of overhead or customer service. Although the intent of the taxonomy is to have consistent cost categories and naming protocols, this differing approach is one example of how some costs may be overstated, understated, or shifted from one cost category to another.

The number of annual installations for an installer likely influences overhead and profit values and how they are reported. The 14 different installers in the dataset represent 13 independently operated companies that install anywhere from 1 to 12 turbines each year and one leasing company that installs between 5 and 40 leased distributed wind systems each year. If an installer only has one project in a year, all overhead costs might be allocated to that one project, whereas an installer with multiple projects can spread overhead costs over the multiple projects.

Installers interviewed for this report recounted success rates of 5% to 50% (i.e., how many potential customers purchase a distributed wind system). Higher customer acquisition success rates and more installations per year could potentially lower installers' overhead costs; however, more analysis is needed to better understand these issues.

Figure 12 shows the overhead and profit project-specific values, including the \$1,716/kW average for residential systems and the \$872/kW average for commercial systems.

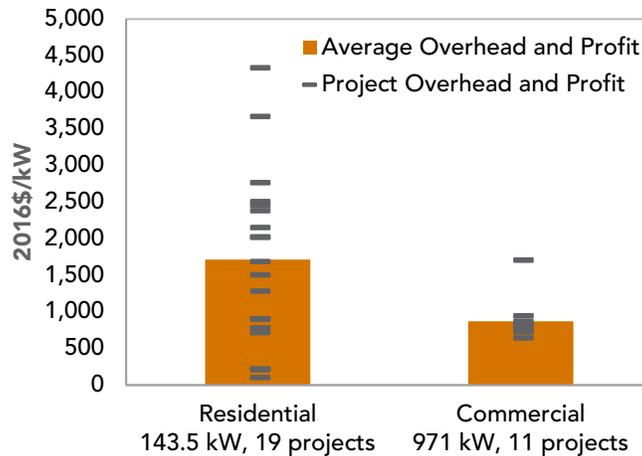


Figure 12. Average and Project-Specific Overhead and Profit

4.3.11 Financing and Transaction Costs

Financing and transaction costs depends on the project’s ownership and business model and include costs associated with project debt, investor due diligence, and investment insurance. No residential or commercial project in this dataset had financing and transaction costs. The leasing company is assumed to have financing costs as part of its business model, but those costs were not provided as itemized project-specific costs. Otherwise, installers reported that the majority of their customers paid cash for their projects, five customers were known to have obtained a bank loan, and two projects received vendor financing, in addition to taking advantage of state and federal incentives when eligible.

4.4 Operations and Maintenance

Operation costs may include land lease payments (typical for utility-scale wind plants, but unusual for behind-the-meter distributed wind projects), remote monitoring, various operations contracts or retainers, insurance, and property taxes. Although operations are a significant expense for wind farms, operation costs, separate from maintenance costs, for small distributed wind projects are typically not significant and were not itemized in this dataset.

Small wind projects do require maintenance. The costs incurred by a maintenance provider (most likely also the project installer) to provide maintenance include costs for labor, travel to the site, consumables, and any other related costs. Quantifying these costs is difficult due to variability in the responsibility of the maintenance, ownership structure, warranty, and warranty status. Some manufacturers cover maintenance costs as part of the manufacturer’s warranty and others do not. Maintenance costs also vary depending on the maintenance provider’s proximity to the project site (i.e., travel costs), the availability of spare parts, and the complexity of maintenance or repairs. In addition, this report uses the cost per kW metric, but an annual cost value may be more informative to a customer. This data-collection effort is the first attempt to standardize how site-visit maintenance costs are tracked and includes non-cost data on travel distance, labor hours, number of maintenance workers, and qualitative information about installer responsibility. Average costs from the dataset are presented here, but more maintenance data are needed to draw noteworthy conclusions.

Maintenance costs can be categorized as scheduled or unscheduled. Reported scheduled maintenance activities included inspecting the turbine, controller, and/or tower; re-torquing blades; checking production meter and communications components; and providing an overall biannual or annual scheduled maintenance visit per the manufacturer’s owner’s manual. Reported unscheduled maintenance

activities included responding to a brush failure; a customer’s complaint of noise from the turbine and a yaw gear issue; replacing the generator, electrical components, inverter, blades, anemometer, or furling cable; fixing or updating communications or supervisory control and data acquisition components; and completing the commissioning process.

Some projects had multiple scheduled and unscheduled maintenance site visits. Installers reported 35 total site visits for 17 residential projects and 9 total site visits for 6 commercial projects for projects installed between 2012 and 2016. No obvious relationship was observed between project installation year and number of visits.

Figure 13 presents the average and visit-specific costs for scheduled maintenance site visits and Figure 14 presents the average and visit-specific costs for unscheduled maintenance site visits. Costs are broken out into average labor costs; average travel costs; and average consumable, parts, and other costs. The average scheduled maintenance visit cost is about \$43/kW for residential and \$16/kW for commercial. The average unscheduled maintenance visit cost is about \$144/kW for residential and \$11/kW for commercial. While the average scheduled maintenance cost for residential systems is in line with the roughly \$44/kW average based on reports from turbine manufacturers and installers for the annual Distributed Wind Market Report (Orrell et al. 2017), the commercial cost averages appear lower and less reliable, most likely because of the small sample size.

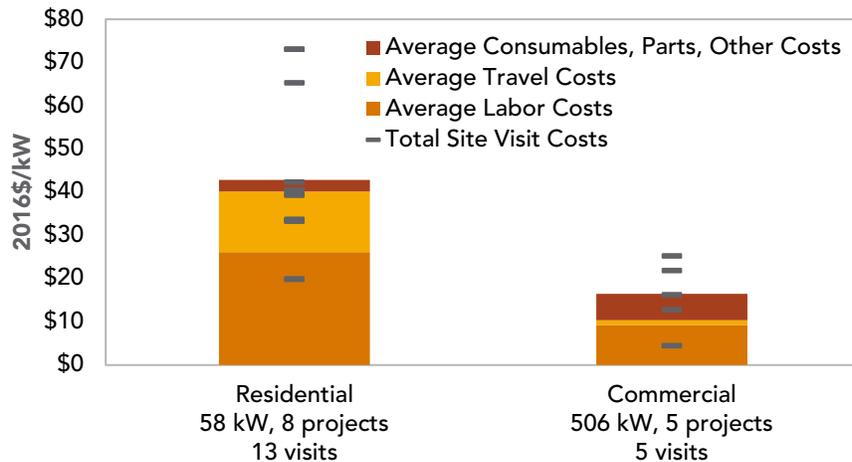


Figure 13. Scheduled Maintenance Site-Visit Costs

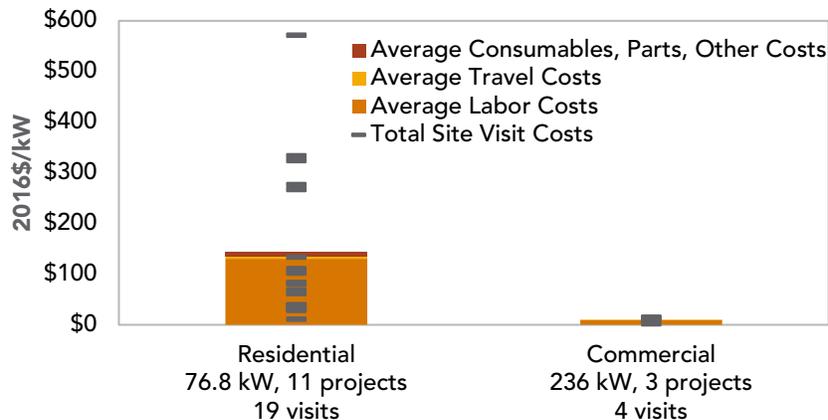


Figure 14. Unscheduled Maintenance Site-Visit Costs

5.0 Conclusions, Next Steps, and Summary

Results from the NREL’s *Assessing the Future of Distributed Wind* report suggest the possibility of a substantial role for behind-the-meter distributed wind in the nation’s electricity future (Lantz et al. 2016). However, to achieve higher levels of adoption, Lantz et al. (2016) noted the necessity of several changes to the current market. These changes consist of not only reductions in technology costs—including cost reductions in balance of plant and installation—but performance improvements, new business models that provide access to low-cost capital and support customer-ready solutions, and increased customer awareness of the benefits of distributed wind technologies. The industry recognizes the importance of cost reduction for distributed wind systems and efforts to that end are currently underway.

The Competitiveness Improvement Project (CIP) awards cost-shared contracts via a competitive process to manufacturers of small and medium wind turbines (DOE 2017). The goals of the CIP are to make wind energy cost competitive with other distributed generation technology and increase the number of wind turbine designs certified to national testing standards. CIP contracts support efforts to reduce hardware costs through value engineering and advanced manufacturing processes, increase system performance through design optimization, and conduct turbine testing for certification of system performance and safety.

The Distributed Wind Energy Association’s (DWEA) Sustainable Manufacturing, Advanced Research & Technology (SMART) Wind Consortium identified and prioritized potential actions that could improve the technology and lower manufacturing costs for support structures (i.e., towers and foundations), turbine systems, electrical subsystems, mechanical parts, and composite parts (DWEA 2016). The DWEA SMART Wind Consortium also identified an opportunity to streamline installation (and maintenance) of distributed wind systems (DWEA 2016). In addition, with its goals of reducing risk and decreasing costs, the Distributed Wind Installers Collaborative can provide another avenue to explore how to reduce installation costs.

5.1 Identifying High Costs

The objective of this report is to provide a cost benchmark of small wind projects in the United States. This benchmark identifies high-cost categories, which can inform potential areas for high-impact cost-reduction opportunities, but does not provide a cost-reduction roadmap or information regarding the susceptibility of each cost category to cost reduction.

Based on the projects analyzed for this report, the highest cost categories, as percentages of total distributed wind system cost, are turbine system equipment, installation, overhead and profit, foundation, electrical infrastructure, and ZPII. The other cost categories (i.e., customer acquisition and qualification, engineering and design, transportation and logistics, taxes, and other costs) represent small percentages of total cost.

5.2 Pathways to Potential Cost-Reduction Opportunities

Cost-reduction opportunities cannot be identified anecdotally. Opportunities need to be vetted with data, such as the multi-year, multi-step effort taken through DOE’s SunShot Initiative for solar PV (Ardani et al. 2013). This report is the first step in distinguishing pathways to potential cost-reduction opportunities for distributed wind.

To move from this benchmark to identifying robust cost-reduction opportunities, the next step is to determine what additional data and analysis are needed to understand the drivers for the high costs and the high variances in some cost categories. Although developing cost models may be appropriate for some cost categories, additional data to expand the sample size is likely to improve the understanding of most cost categories. Further, analyzing Tier 3 and 4 costs could identify the specific drivers for Tier 2 costs to help determine whether certain costs can be addressed via research and development efforts. Future work would then include identifying actions that industry and DOE could take to lower those costs.

5.2.1 Wind Turbine System Equipment

Representing a significant portion of total system cost, wind turbine system equipment (i.e., turbine, tower, and optional equipment) accounts for 37% of the total average residential project cost and 59% of the total average commercial project cost. The tower accounts for 33% of the turbine system equipment cost for residential systems and 20% for commercial systems. These large percentages warrant exploring cost reductions for turbine system equipment, particularly for commercial systems. Larger turbines are expected to have lower costs per kW than smaller turbines; however, that was not true for this dataset. More data and analysis are needed to understand if this apparent discrepancy was due to the small commercial sample size or other reasons, and if any other components, besides the tower, are significant cost drivers.

5.2.2 Installation

Installation costs represent 21% of the total average residential system cost. While commercial systems appear to have high turbine system equipment costs, they have lower installation costs at 7% of the total average commercial system cost.

A breakdown of installation costs (i.e., labor, crane, and materials) was not available for a substantial number of residential projects. Therefore, to understand the high residential installation costs and identify cost-reduction opportunities, more detailed data must be collected so that lower-tier installation cost category information can be analyzed.

5.2.3 Overhead and Profit

The overhead and profit values reported by installers are dependent on many variables and therefore may be overstated or understated. The average overhead and profit values, 14% and 12% for residential and commercial projects, respectively, likely reflect assessment costs for unsuccessful projects and a low number of annual installations. Higher customer acquisition success rates and more installations per year could potentially lower installers' overhead costs; however, more analysis is needed to better understand these issues. NREL's solar PV cost benchmarking effort, as part of the SunShot Initiative, relied on in-depth interviews with members of financing departments at large PV installation companies on the subjects of third-party financing, overhead costs, and corporate public filings, to refine its cost model (Freidman, et al. 2013). A similar approach for distributed wind may be appropriate; although, the same public information will not be available and distributed wind installers and developers are not typically large companies.

5.2.4 Foundation

Foundation costs are complex and driven by many variables. The dataset used in this report, and the market in general, suggest that no single foundation type and design works for all distributed wind systems. Turbine size, tower height, tower type, and geotechnical conditions all impact foundation design and cost. Foundation designs appropriate for multiple tower types and geographic regions and a range of standardized towers could be promising cost-reduction efforts (DWEA 2016). A modeling approach,

validated with the data collected for this report, is recommended to understand foundation costs and cost averages. This will allow analysis of the relationships between all the variables, including labor, materials, and equipment, to understand potential areas for cost savings.

5.2.5 Electrical

Electrical infrastructure costs are roughly equal for both system size classes, about 5% of total cost for residential systems and 6% for commercial systems. Given that basic electrical work (i.e., wiring) is not unique to distributed wind systems, further analysis on what drives electrical costs, and the range exhibited in the residential costs, is needed to identify potential reduction opportunities. For example, although basic electrical labor is not unique to distributed wind, equipment, such as inverters, may not be optimized for small wind. Understanding Tier 3 costs, particularly the use of in-house labor, equipment, and materials versus the use of contracted labor, equipment, and materials, will provide insight into the cost drivers.

5.2.6 ZPII

ZPII costs are more significant than some other costs, but do not account for a large percentage of overall average costs. Further, because ZPII costs comprise several permits and processes, multiple cost-reduction efforts would be required to influence ZPII costs.

Some potential ZPII cost-reduction opportunities were identified using the current dataset. Installers reported lower utility interconnection costs for projects that required shorter (i.e., four pages or less) interconnection forms. Additional data representing a wide cross-section of utility types are needed to substantiate this preliminary finding.

Foundation design and geotechnical report costs account for 25% to 100% of the building/structural permit cost. Therefore, addressing foundation design requirements, both through the possibility of standardized designs and with the authorities who control foundation design requirements, may have the benefit of reducing building/structural permit costs.

Processing and transaction costs for obtaining incentives represent 16% of total ZPII costs for residential systems and 10% for commercial systems. Simplifying incentive requirements and applications may help lower incentive processing and transaction costs; however, efforts to that end must not hamper the ability of incentive programs to fund quality distributed wind projects.

The taxonomy is useful to track the ZPII costs of successful projects; however, ZPII costs can considerably impact distributed wind adoption. Developers and installers may incur costs for projects that are not ultimately installed (e.g., because a zoning variance was not obtainable), but also proactively avoid certain jurisdictions because the strict regulations prohibit cost-effective projects, because of high fees, onerous interconnection requirements, or height limitations that would reduce energy generation potential.

Tracking the reasons for failed projects is outside of the taxonomy; however, understanding the tipping point when ZPII costs become ZPII barriers through a modeling approach, may inform potential cost-reduction opportunities that could increase distributed wind adoption. So, while reducing ZPII costs would not have a significant impact on average distributed wind system costs, it could have a substantial impact on distributed wind adoption.

5.2.7 Other Costs

Transportation and logistics, taxes, engineering and design, and other costs account for small amounts of the overall average distributed wind system cost, but may still be areas for low-impact cost-reduction opportunities.

Of these other costs, transportation and logistics costs is the strongest candidate for cost-reduction opportunities. While installers reported turbine system equipment transportation costs, not all reported how or from where the equipment was shipped or separate shipping costs for the tower and turbine, if applicable. Because of the various shipping and delivery methods and starting points, more detailed data are needed to understand these costs and the potential for cost-reduction opportunities (e.g., through shipping standardization).

Taxes may not be a target for robust cost-reduction opportunities. However, to reduce reliance on installer reports, future analysis of taxes and their impact on distributed wind costs could be estimated using published tax rates and information from tax exemption incentive programs.

5.3 Summary

Industry stakeholders have indicated that understanding and reducing distributed wind system costs is a priority. The development of an industry-reviewed distributed wind cost taxonomy allowed for the small wind cost benchmarks presented herein. Obtaining additional data to expand the dataset sample size, developing cost models for certain cost categories, and diving into the lower-tier costs are the required next steps to move from this initial cost benchmark to identifying robust and data-driven cost-reduction opportunities. Reducing distributed wind costs will increase distributed wind's competitiveness and expand the U.S. distributed wind market.

6.0 References

Ardani K, D Seif, R Margolis, J Morris, C Davidson, S Truitt, and R Torbert. 2013. *Non-Hardware ("Soft") Cost-Reduction Roadmap for Residential and Small Commercial Solar Photovoltaics, 2013-2020*. NREL/TP-7A40-59155. National Renewable Energy Laboratory. Golden, Colorado. Available at <https://www.nrel.gov/docs/fy13osti/59155.pdf>.

DWEA (Distributed Wind Energy Association). 2016. *SMART Wind Roadmap: A Consensus-Based, Shared-Vision Sustainable Manufacturing, Advanced Research & Technology Action Plan for Distributed Wind*. Washington, DC: U.S. Department of Commerce. Available at <http://distributedwind.org/wp-content/uploads/2016/05/smart-wind-roadmap.pdf>.

Freidman B, K Ardani, D Feldman, R Citron, R Margolis, and J Zuboy. 2013. *Benchmarking Non-Hardware Balance-of-System (Soft) Costs for U.S. Photovoltaic Systems, Using a Bottom-Up Approach and Installer Survey – Second Edition*. NREL/TP-6A20-60412. National Renewable Energy Laboratory. Golden, Colorado. Available at <https://www.nrel.gov/docs/fy14osti/60412.pdf>.

Forsyth T, T Jimenez, R Preus, S Tegen, and I Baring-Gould. 2017. *The Distributed Wind Cost Taxonomy*. NREL/TP-5000-67992. National Renewable Energy Laboratory. Golden, Colorado. Available at <https://www.nrel.gov/docs/fy17osti/67992.pdf>.

Lantz E, B Sigrin, M Gleason, R Preus, and I Baring-Gould. 2016. *Assessing the Future of Distributed Wind: Opportunities for Behind-the-Meter Projects*. NREL/TP-6A20-67337. National Renewable Energy Laboratory, Golden, Colorado. Available at <http://www.nrel.gov/docs/fy17osti/67337.pdf>.

Orrell A, N Foster, J Homer, and S Morris. 2017. *2016 Distributed Wind Market Report*. PNNL-26540. Richland, Washington: Pacific Northwest National Laboratory. Available at <http://energy.gov/eere/wind/downloads/2016-distributed-wind-market-report>.

DOE (U.S. Department of Energy). 2017. *Distributed Wind Competitiveness Improvement Project Fact Sheet*. Available at <https://energy.gov/eere/wind/downloads/distributed-wind-competitiveness-improvement-project-fact-sheet>.

Appendix A: Data-Collection Process

The Pacific Northwest National Laboratory (PNNL) and National Renewable Energy Laboratory (NREL) team conducted two rounds of data collection; one in the spring of 2016 and one in early 2017. From these two rounds, project data were collected from a total of 17 installers with projects in 20 states.

Potential installers to interview were identified by leveraging PNNL and NREL relationships with installers fostered through industry events, manufacturers' distribution networks, and other distributed wind research activities. Eligible installers were required to have had distributed wind projects installed in 2012 or since; to have all specific, itemized cost records for those projects; and be able to provide that information within the requested timeline. Because of the effort requested, compensation was offered to the selected installers. However, even with compensation, the eligibility criteria limited the number of installers. To illustrate this point, 30 installers were considered in the first round of data collection, but only 10 were able to participate.

In the first round, conducted in the spring of 2016, 10 installers were interviewed and 30 projects were added to the dataset. Some of these projects included mid-size (101 kW to 1 MW) and large-scale (greater than 1 MW) turbine projects. Round 2 data collection, limited to small wind installers, added 7 installers and 52 projects to the dataset.

Installers first completed forms and then were interviewed by a PNNL or NREL team member to verify or clarify responses. Round 1 of data collection used an Excel spreadsheet as the response form; Round 2 used several web-based Google Forms. The form format changed between Round 1 and Round 2 based on lessons learned and feedback from Round 1.

In addition to specific costs, installers reported other project information (e.g., utility type, jurisdiction type, and customer type).

To help standardize answers and keep the response form user friendly, two Google Forms were created for Round 2: the Project Data Input Sheet (shown in Table A.1) and the General (Installer) Input Form (shown in Table A.2). The Project Data Input Sheet contained 272 questions with entry fields based on the taxonomy and focused on detailed information about the specific projects. The General (Installer) Input Form contained 32 questions and focused on general, non-project-specific information including barriers to increased deployment and company marketing strategies.

In addition, a short response form was created to try to capture typical, or average, cost data from a wider installer pool. This request did not require the installer to have detailed cost information, and no compensation was provided. This approach yielded three responses; the quantitative answers were not incorporated into the analysis presented in this report, but the qualitative answers helped inform the report narrative.

After Round 2 data collection was completed, the data collected in Rounds 1 and 2 were combined and organized. Text-based answers were standardized as appropriate and other edits were made to create a cohesive dataset for analysis.

Table A.1. Project Data Input Sheet

PROJECT DATA INPUT SHEET

Project Name

Installer Name

Could you provide a high-res photo of this project

May we use this project as a case study

Comments

TURBINE INFORMATION

Year of installation

Turbine Manufacturer

Turbine Model

of Turbines in Project

Turbine Rated Power (kW)

Turbine Rotor Diameter (m)

Tower Type

Tilt-down?

Hub Height (m)

Foundation Type

Estimated annual energy production (kWh)

Average hub height wind speed (m/s)

Comments

SITE INFORMATION

Customer Category

Project Location (State)

Project Location (County)

Project Latitude (deg)

Project Longitude (deg)

Project Elevation (m)

Jurisdiction Name (that has zoning approval/disapproval)

Jurisdiction Type (that has zoning approval/disapproval)

Is this your (or your firm's) first project in this jurisdiction?

Is this the first project of this type in this jurisdiction?

Interconnecting Utility Name

Interconnecting Utility Type

Comments

PROJECT INFORMATION

Project Organization & your company's role

Total Project Cost (\$)

Cost Exclusions

Other Costs Incurred by End User

Was this project unusual in any way?

Comments

Table A.1. (contd)

TURBINE SYSTEM EQUIPMENT

Turbine (Price to installer) (\$)
Tower Components (provided by OEM) (\$)
Tower Components (not provided by OEM) (\$)
Options/Other Turbine equipment costs (\$)
Turbine (Price to End User) (\$)
Tower (Price to end user)(\$)
Comments

TRANSPORTATION AND LOGISTICS

Shipping from OEM (to installer or customer) (\$)
Delivery to Customer (If not shipped directly from OEM) (\$)
Warehousing/Storage (\$)
Comments

ZONING

Fees (\$)
Calendar time (days)
Labor hours (hr)
Labor cost (\$)
Other (\$)
Describe the zoning approval process for this project
Comments

PERMIT (BUILDING/STRUCTURAL)

Fees (\$)
Calendar time (days)
Labor time (hr)
Labor cost (\$)
Foundation Design (\$)
Geotech Report (\$)
Stamped Tower Structural / Engineer to Stamp Plans (\$)
Consultants/Studies (Other) (\$)
Other (\$)

PERMIT (ELECTRICAL)

Fees (\$)
Calendar time (days)
Labor time (hr)
Labor cost (\$)
Consultants/Studies (Electrical Design) (\$)
Other (\$)
Comments

PERMIT (FAA)

Fees (\$)
Calendar time (days)
Labor time (hr)
Labor cost (\$)
Consultants/Studies (\$)
Other (\$)
Comments

Table A.1. (contd)

PERMIT (ENVIRONMENTAL)

Fees (\$)
Calendar time (days)
Labor time (hr)
Labor cost (\$)
Consultants/Studies (\$)
Other (\$)
Comments

PERMIT (EROSION & SEDIMENT CONTROL)

Fees (\$)
Calendar time (days)
Labor time (hr)
Labor cost (\$)
Consultants/Studies (\$)
Other (\$)
Comments

OTHER PERMIT 1

Permit Name
Fees (\$)
Calendar time (days)
Labor time (hr)
Labor cost (\$)
Consultants/Studies (\$)
Other (\$)
Comments

OTHER PERMIT 2

Permit Name
Fees (\$)
Calendar time (days)
Labor time (hr)
Labor cost (\$)
Consultants/Studies (\$)
Other (\$)
Comments

UTILITY INTERCONNECTION

Fees (\$)
Form length (long/short)
Calendar time (days)
Labor time (hr)
Labor cost (\$)
Consultants/Studies (\$)
Other (\$)
Comments

Table A.1. (contd)

INCENTIVE PROCESSING & TRANSACTION COSTS (#1)

Incentive Name
Fees (\$)
Calendar time
Labor time (hr)
Labor cost (\$)
Other (\$)
Incentive value (\$)
Comments

INCENTIVE PROCESSING & TRANSACTION COSTS (#2)

Incentive Name
Fees (\$)
Calendar time
Labor time (hr)
Labor cost (\$)
Other (\$)
Incentive value (\$)
Comments

INCENTIVE PROCESSING & TRANSACTION COSTS (#3)

Incentive Name
Fees (\$)
Calendar time
Labor time (hr)
Labor cost (\$)
Other (\$)
Incentive Value (\$)
Comments

ENGINEERING AND DESIGN

Site-Assessment Costs (\$)
Wind Resource Assessment (WRA) (\$)
Site plans / layout (\$)
Engineering Studies/Consulting/Professional Services (\$)
Inspections/Oversight/Misc. Testing (\$)
Comments

OVERHEAD, INDIRECT, AND OTHER COSTS (INCLUDING PROFIT) (\$)

Other Development & Project Management Costs (\$)
Construction Management (\$)
Overhead & Profit (\$)
Sales Taxes (\$)
Import Taxes (\$)
Comments

CONSTRUCTION: OVERVIEW

Construction Overview

Table A.1. (contd)

CONSTRUCTION: SITE PREP & CLEAN UP

Site prep labor (\$)
Site prep equipment (\$)
Site prep material (\$)
Site prep subcontracts (\$) (that can't be itemized above)
Comments

CONSTRUCTION: FOUNDATION

Foundation labor (\$)
Foundation equipment (\$)
Foundation material (\$)
Foundation subcontracts (\$) (that can't be itemized above)
Comments

CONSTRUCTION: ELECTRICAL

Electrical labor (\$)
Electrical equipment (\$)
Electrical material (\$)
Electrical subcontracts (\$) (that can't be itemized above)
Comments

CONSTRUCTION: TURBINE & TOWER INSTALLATION

Installation labor (\$)
Installation equipment (except for crane) (\$)
Crane size/rating
Crane cost (\$)
Crane mob & demob (\$)
Installation material (\$)
Installation subcontracts (\$) (that can't be itemized above)
Comments

CONSTRUCTION: COMMISSIONING

Commissioning labor (\$)
Commissioning equipment (\$)
Commissioning material (\$)
Comments

CONSTRUCTION: "OTHER" COSTS

Other labor (\$)
Other equipment (\$)
Other material (\$)
"Other" subcontracts (\$) (that can't be itemized above)
Comments

FINANCING

How was this project financed?
Financing acquisition & due diligence support (labor) (\$)

Table A.2. General (Installer) Input Form

GENERAL COMPANY INFORMATION

Name of person filling out form
Company name
Other work
of turbines installed/year, types (2016)
of turbines installed/year, types (2015)
of turbines installed/year, types (2014)
of turbines installed/year, types (2013)
of turbines installed/year, types (2012)
Comments

OVERHEAD
Workplace training description
Workplace training (days/year/employee)
What are workplace training costs (\$/year/employee)
Licensing, bonding, insurance description
Licensing, bonding, insurance (\$/year)
Marketing, Advertising & Sales description
Marketing & Advertising Costs (\$/year)
Sales Costs (\$/year)
Major equipment items owned by firm
Other Overhead Description
Other Overhead Costs (\$/year)
Comments

PROJECT EXECUTION
Customer qualification process
Installation process
Who (or job title) handles Zoning, Permitting, Interconnection, Incentives Processing
Comments

BARRIERS
Project success rate
Causes of projects falling through
Avoided Jurisdictions?
Biggest Barriers (in general)
Biggest Barriers (for your firm)

LAST WORDS
Anything else you want to tell us

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