LandBOSSE in SAM (Tutorial/Documentation)

Contents

Introduction

NREL's Land-based Balance of System Systems Engineering (LandBOSSE) model is a tool for modeling the balance-of-system (BOS) costs of land-based wind plants. BOS costs currently account for approximately 30% of the capital expenditures needed to install a land-based wind plant; they include all costs associated with installing a wind plant, such as permitting, labor, material, and equipment costs associated with site preparation, foundation construction, electrical infrastructure, and tower installation. This document serves as a tutorial for successfully running the newly integrated LandBOSSE model in the System Advisor Model (SAM).

For more details on how the LandBOSSE model calculates BOS costs, see the following technical report: https://www.nrel.gov/docs/fy19osti/72201.pdf .

The LandBOSSE tool is a an open-source project written in the Python programming language. It is maintained by NREL and is hosted on GitHub. For more details on the code implementation of the model, see the following link to LandBOSSE's GitHub repository: https://github.com/wisdem/landbosse .

For a detailed look at the default LandBOSSE inputs used in SAM, see the following two links:

1. https://github.com/WISDEM/LandBOSSE/blob/pip_installable/landbosse/landbosse_api/project_list.xlsx
2. https://github.com/WISDEM/LandBOSSE/tree/pip_installable/landbosse/landbosse_api/project_data

LandBOSSE Inputs in SAM

The LandBOSSE model has 66 inputs: 44 input parameters (e.g., turbine rating, distance to interconnection, etc.) and 12 data lookup tables (e.g., crew cost for multiple types of crews). However, the version of LandBOSSE used in SAM has a condensed set of **14** inputs which were identified to have the highest impact on a utility scale project's total Balance-of-Station (BOS) costs. Table 1 below lists all 14 LandBOSSE inputs in SAM that define a unique project.

Table 1: LandBOSSE User Inputs in SAM

LandBOSSE Input	Description	Which page/tab can this user input be defined in?	Default Value
Wind Resource	Wind resource of the project site. **Note:** LandBOSSE can only run for hourly weather data.	**Page:** Wind Resource	Southern WY - flat lands
Interconnect voltage (kV)	Voltage (in kV) of the interconnection the project will tie into.	**Page:** System Costs **Tab:** Land-based Balance-of-System Cost Model *(Balance of System Model Inputs)*	137
Distance to interconnect (miles)	Distance (in miles) between the substation and the point of interconnection to the grid.	**Page:** System Costs **Tab:** Land-based Balance-of-System Cost Model *(Balance of System Model Inputs)*	10
Turbine foundation depth (m)	Depth (in meters) of the wind turbine foundation. LandBOSSE uses the shallow, spread-foot foundation design type. Refer to the technical report on more information on turbine foundation calculation.	**Page:** System Costs **Tab:** Land-based Balance-of-System Cost Model *(Balance of System Model Inputs)*	2.36
Turbine rated thrust (N)	Maximum force experienced by the wind turbine under extreme conditions that will dictate the wind turbine's foundation design.	**Page:** System Costs **Tab:** Land-based Balance-of-System Cost Model *(Balance of System Model Inputs)*	5.89e+05
Labor cost multiplier	Multiplier for all labor costs used in the mode. Refer to the tech report for a breakdown of the labor type used by the project.	**Page:** System Costs **Tab:** Land-based Balance-of-System	1

		Cost Model *(Balance of System Model Inputs)*	
50-year gust velocity	Velocity of an extreme 50-year wind gust (in m/s).	**Page:** System Costs **Tab:** Land-based Balance-of-System Cost Model *(Balance of System Model Inputs)*	59.50
Number of turbines	Number of turbines can be set in.3 different ways in the Wind Farm page in SAM: 1) Use a single turbine **Note: LandBOSSE will only run for 11 or more turbines. This option will return an error when running LandBOSSE.** 2) Specify desired farm size. **Note: Turbine and row spacing are fixed defaults in this option and cannot be changed by the user. BOS cost is very sensitive to turbine and row spacing; therefore, this is not the best option for running LandBOSSE.** 3) Specify number of turbines. **Note: This is the best option when running LandBOSSE in SAM.**	**Page:** Wind Farm	100
Turbine Spacing (times rotor diameter)	Distance between each turbine within any given row in the project. This input is a multiplier and its units are *times rotor diameter*. That is, distance between each turbine in any given row is equal to:	**Page:** Wind Farm **Tab:** Turbine Layout	4

	*(user defined multiplier * rotor diameter)*		
Row Spacing (times rotor diameter)	Distance between each turbine row in the project. This input is a multiplier and its units are *times rotor diameter*. That is, distance between each row is equal to: *(user defined multiplier * rotor diameter)*	**Page:** Wind Farm **Tab:** Turbine Layout	10
Machine rating (MW)	Wind turbine machine rating. This is a function of the wind turbine selected by the user from SAM's turbine library.	**Page:** Wind Turbine **Tab:** Wind Turbine	1.5
Hub height (m)	Wind turbine hub height in meters.	**Page:** Wind Turbine	80
Rotor diameter (m)	Wind turbine rotor diameter in meters. This is a function of the wind turbine selected by the user from SAM's turbine library.	**Page:** Wind Turbine	77
Wind shear Exponent	The shear coefficient is a measure of the variation in wind speed with height above the ground at the turbine installation site. Refer to the LandBOSSE technical report for more information on how wind shear exponent is used in BOS calculations.	**Page:** Wind Turbine	0.20

Workflow for Running LandBOSSE in SAM

1. LandBOSSE in SAM currently only runs for 11 or more turbines, and for turbine ratings in the range of 1 thru 8 MW machine ratings. Accordingly, when running the Wind technology model in SAM, make sure to only select a financial model within the *Power Purchase Agreement* dropdown (Figure 1).

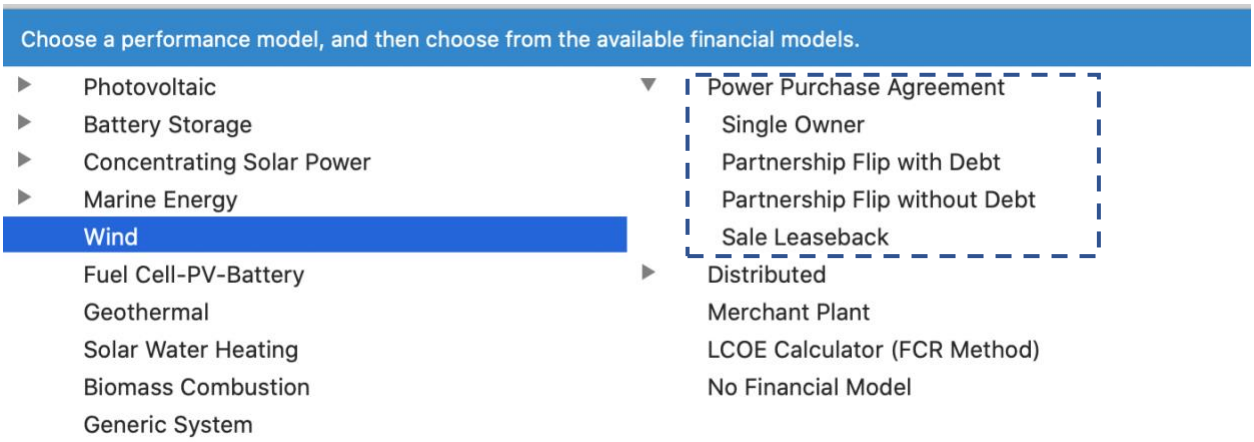

Figure 1: Startup Screen in SAM. Choose a financial model with the Power Purchase Agreement dropdown when you want to run LandBOSSE

2. Once you have selected the appropriate financial model, the LandBOSSE model can be found in the *System Costs* Page (Figure 2).

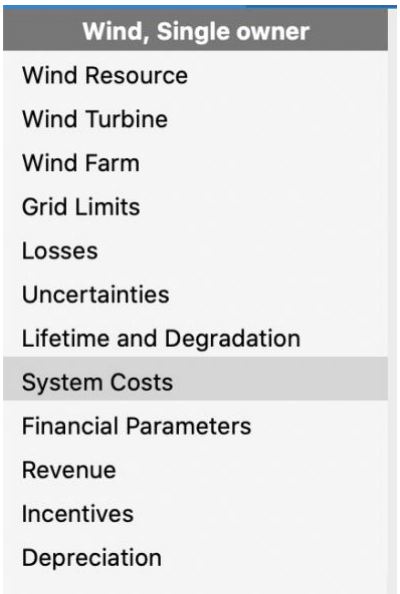

Figure 2: The LandBOSSE model is located within the *System Costs* page

3. Fill in the LandBOSSE inputs in SAM (see Figure 3) to the best of your knowledge. Please note the text boxes in white represent fields that can be edited by the user, and the text boxes in blue (Project Specifications column) represent fields that are set by the user, but in a **different** page in SAM. Please refer to Table 1, to locate the page(s) where the value in the text boxes in blue can be edited.

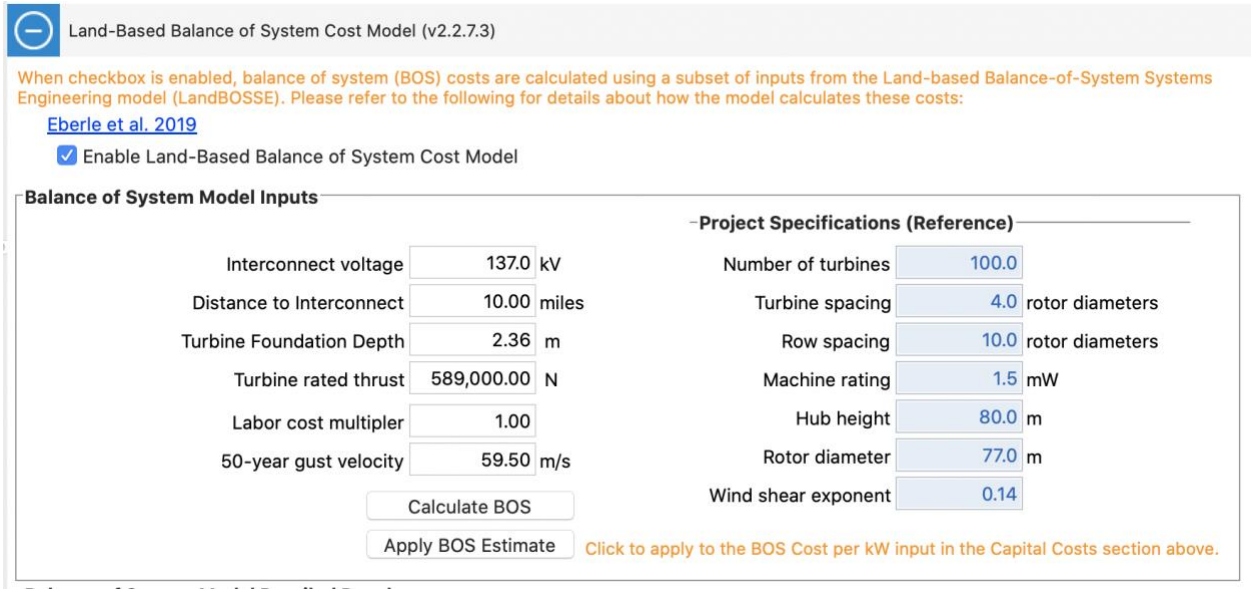

Figure 3: Choose a financial model with the Power Purchase Agreement dropdown when you want to run LandBOSSE

4. Once all 14 inputs have been set, click on the *Calculate BOS* button (Figure 3). Once the run is successfully complete, the detailed set of results calculated by LandBOSSE will be displayed in the *Balance of System Model Detailed Results* tab.

5. *Important:* If you would like to replace SAM's default *Balance of System cost* (Figure 4), with the calculated total BOS cost ($/kW), click on the *Apply BOS Estimate*. This is an important step if you are attempting run an entire SAM simulation and you would like to use the BOS cost estimated by LandBOSSE.

   That is, *Apply BOS Estimate* button will replace the default $/kW BOS cost (Figure 4) with the BOS cost calculated by LandBOSSE.

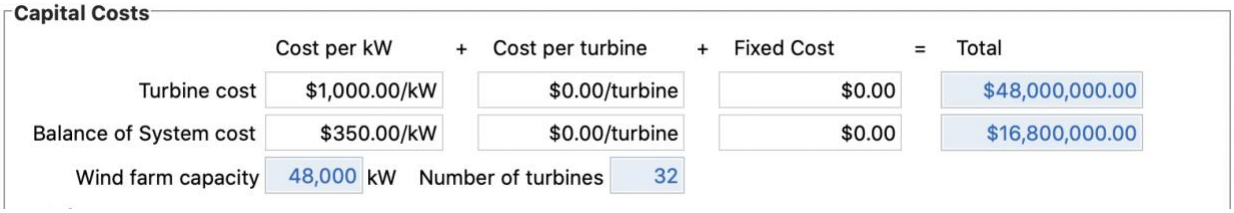

Figure 4: Clicking on Apply BOS Estimate will replace the default BOS Cost per kW in SAM

Automatic Update of Backend Default Data

Since only 14 out of the 66 LandBOSSE inputs are exposed to the user for editing, the remaining LandBOSSE are set to default inputs in the backend, and these cannot be changed by the user. However, some of the default inputs in the backend that scale according to the 14 user defined inputs are automatically updated when the user clicks on the *Calculate BOS* button (Figure 3). For a detailed summary of the LandBOSSE inputs that are updated in/by SAM, please see Table 2.

Please see table A1 (Appendix), for a list of inputs that do not get updated when the user clicks the *Calculate BOS* button. See Table A2 for a list of the publicly available data sources (per turbine) used to derive wind turbine scaling relationships. These scaling relationships enabled the implementation of automatic updates to the default backend input data upon clicking the *Calculate BOS* button.

Table 2: List of LandBOSSE inputs and accompanying description of whether the input is updated when the user runs LandBOSSE in SAM.

LandBOSSE Input	Description	Updated in or by SAM?
labor_cost_multiplier	Multiplier for labor costs	Updated in SAM user interface by the user
Rsmeans	Project construction database	Labor costs in this database are updated based on user defined labor cost multiplier in SAM user interface
component_data	Database containing turbine components	This database gets updated when the user does any or all of the following: 1) Select a turbine in SAM's wind turbine library 2) Change hub height
Mass tonne (component_data)	Component weight (in tonnes). This item is a field in the component_data database	Gets automatically updated on running SAM, based on scaling relations described in this memo
Lift height m (component_data)	Height to which the unique turbine component must be lifted	Gets automatically updated on running SAM, based user defined hub height
Surface area sq m (component_data)	Surface area (in m^2) of the unique turbine component	Gets automatically updated on running SAM, based on scaling relations described in this memo
Section height m (component_data)	Height (in m) of the unique turbine component	Gets automatically updated on running SAM, based user defined hub height

Lever arm m (component_data)	Perpendicular distance from the component's axis of rotation to the line of action of the force.	Gets automatically updated on running SAM, based on scaling relations described in this memo
num_turbines	Number of turbines in project	Updated in SAM user interface by the user
construct_duration	Project construction duration in months	Not updated
hub_height_meters	Turbine hub height	Updated in SAM user interface by the user
rotor_diameter_m	Turbine rotor diameter in meters	Updated in SAM user interface by the user
wind_shear_exponent	Wind shear exponent	Updated in SAM user interface by the user
turbine_rating_MW	Turbine rating in MW	Updated in SAM user interface by the user
rate_of_deliveries	Rate of deliveries	Updated in SAM user interface by the user
turbine_spacing_rotor_diameters	Turbine spacing (times rotor diameter)	Updated in SAM user interface by the user
depth	Turbine foundation depth	Updated in SAM user interface by the user
rated_thrust_N	Turbine rated thrust (N)	Updated in SAM user interface by the user
bearing_pressure_n_m2	Soil bearing pressure (N/m_2)	Not updated
gust_velocity_m_per_s	50-year peak gust velocity (m/s)	Updated in SAM user interface by the user
project_size_megawatts	Project size (in MW)	Updated in SAM user interface by the user.
row_spacing_rotor_diameters	Turbine row spacing (times rotor diameter)	Updated in SAM user interface by the user
distance_to_grid_connection_km	Distance to grid connection (km)	Updated in SAM user interface by the user
trench_len_to_substation_km	Trench length from each string to the substation	Calculated in LandBOSSE
distance_to_interconnect_mi	Distance to interconnection (in miles)	Updated in SAM user interface by the user
interconnect_voltage_kV	Interconnect voltage (in kV)	Updated in SAM user interface by the user
weather_window	Weather window	Calculated in LandBOSSE based on weather data provided by SAM

If the user would like to manually be able to edit all 66 of LandBOSSE inputs, please download LandBOSSE directly from: https://github.com/WISDEM/LandBOSSE .

Running BOS Parametrics in SAM

Users can now run parametric analyses in SAM to study the impact on BOS cost from the 14 LandBOSSE inputs. The steps to do this are as follows:

1. Set up a project to the best of your knowledge following steps outlined in the *Workflow for Running LandBOSSE in SAM* section.

2. To run parametrics, select the *Parametrics* option as found in the bottom left corner in the SAM window.

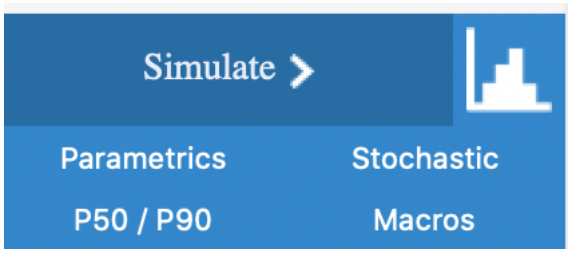

Figure 5: Simulation options available in the System Advisory Model (SAM) as seen in the lower left corner in of the main SAM user interface.

3. Click on the *Quick Setup* option (Figure 6) and search for "LandBOSSE" to filter LandBOSSE inputs you would like to run parametrics for.

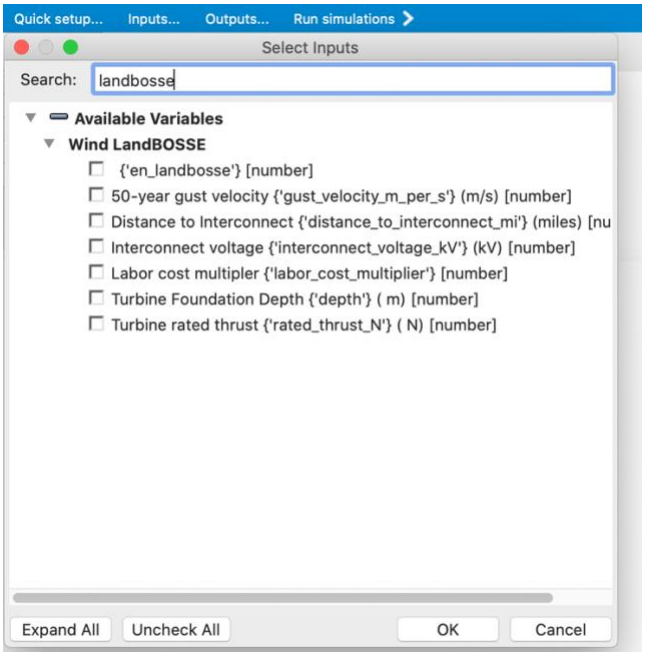

Figure 6: LandBOSSE inputs for running parametrics in SAM

Please note that not all BOS inputs are filtered under the "LandBOSSE" keyword since the remaining of the 14 BOS inputs are also inputs to the rest of the Wind technology

model (not just to LandBOSSE). These remaining inputs (see Table 1) can be found using appropriate search keywords.

4. Once you have selected the search parameters for your parametric analyses, and the relevant output (total BOS cost for instance), click on *Run Simulation* (Figure 6). Figure 7 shows a sample output from a successful parametric analysis of total project BOS cost as a function of *labor_cost_multiplier*, wind_turbine_hub_ht , and *turbine_spacing* which are all LandBOSSE inputs.

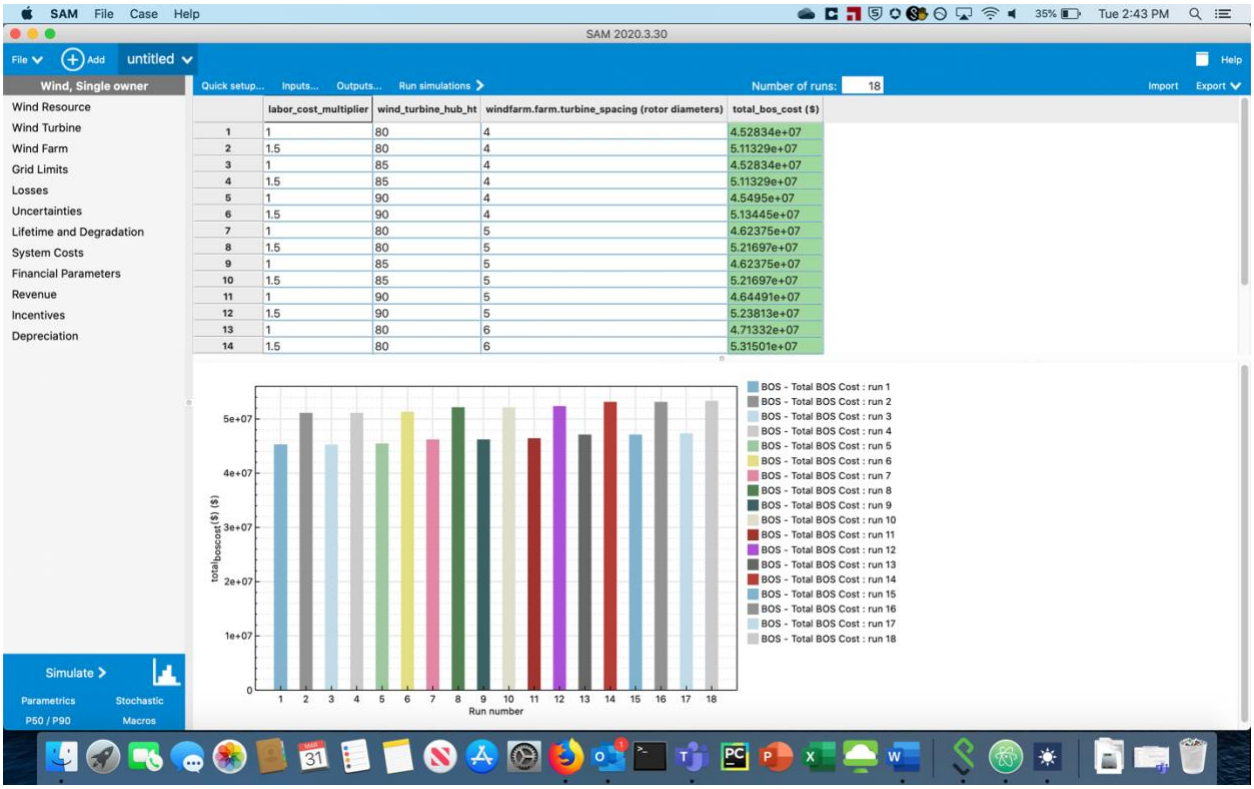

Figure 7: Sample parametric run in SAM using LandBOSSE inputs

Appendix

Table A1. List of LandBOSSE inputs and accompanying description of whether the input is updated when the user runs LandBOSSE in SAM.

LandBOSSE Input	Description	Updated in or by SAM?
site_facility_building_area_df	Site facility building area database. Building areas broken down into various buckets based on project size	Not updated
material_price	Construction material prices database	Not updated
development_df	Project development cost database.	Not updated
Cycle time installation hrs (component_data)	Time needed to install the component	Not updated
Offload hook height m (component_data)	Hook height required to life the component	Not updated
Offload cycle time hrs (component_data)	Time required to offload the component	Not updated
Multiplier drag rotor (component_data)	What aspect of the component is involved in drag calculations for lifting (erection)	Not updated
Multiplier tower drag (component_data)	What aspect of the component is involved in drag calculations for the tower (foundation design)	Not updated
cable_specs_pd	Database containing electrical specifications and cost data for power cables used in the project.	Not updated
crane_breakdown_fraction	Number of times a crane must be broken down between turbines (often an indication of the complexity of the site and the size of the crane and components)	Not updated
breakpoint_between_base_and--_topping_percent	Breakpoint between base and topping (%)	Not updated
fuel_usd_per_gal	Fuel cost per gallon ($/gal)	Not updated
bearing_pressure_n_m2	Soil bearing pressure (N/m^2)	Not updated
road_length_adder_m	Road length adder	Not updated
fraction_new_roads	Fraction of all roads that will be constructed in this project	Not updated
road_quality	Quality of road that will be maintained and/or constructed by the project	Not updated

line_frequency_hz	Transmission line's operating frequency (Hz)	Not updated
user_defined_distance_to--_grid_connection	User defined distance to grid connection	N/A
crew	Database of types of crew required in the project	Not updated
crew_cost	Database of hourly costs of various crew members	Not updated
rsmeans_per_diem	Per diem rate	Not updated
user_defined_home_run_trench	User defined homerun trench length	N/A
new_switchyard	Will the project require a new switchyard? (yes/no)	Not updated
critical_speed_non_erection_wind--_delays_m_per_s	Critical wind speed for non-erection construction activities	Not updated
critical_height_non_erection--_wind_delays_m	Critical height (in m) above which non-erection activities will be delayed/impacted by the critical wind speeds	Not updated
road_width_ft	Width of road(s) to be constructed	Not updated
road_thickness	Thickness of road(s) to be constructed	Not updated
crane_width	Width of crane(s) required by the project (in m)	Not updated
num_hwy_permits	Number of highway permits required for the project	Not updated
num_access_roads	Number of access roads in this project	Not updated
overtime_multiplier	Labor over time multiplier	Not updated
markup_contingency	Project markup contingency (%)	Not updated
markup_warranty_management	Project markup warranty management (%)	Not updated
markup_sales_and_use_tax	Markup, sales, and use tax (%)	Not updated
markup_overhead	Markup overhead (%)	Not updated
markup_profit_margin	Markup profit margin	Not updated
season_construct	Season construct	Not updated
time_construct	Working hours (12 vs. 24)	Not updated

Table A2: List of publicly available data sources used to obtain turbine component data (note: this is a list of turbines currently in the SAM library).

Turbine Make (in SAM Library)	Link to Data Source
NEG Micon 52 900	Wind-Turbine-Models.com
Vergnet GEV 1000 kW	Website of Vergnet
Nordic 1000 54m 1000kW	Wind-Turbine-Models.com
Bonus 1300	Wind-Turbine-Models.com
Nordex N60-1300	Website of OEM - Nordex
Fuhrlander FL 1500_70	Wind-Turbine-Models.com
Fuhrlander FL 1500_77	Wind-Turbine-Models.com
GE 1.5 xle	Wind-Turbine-Models.com
GE 1.5s	Wind-Turbine-Models.com
GE 1.5sle	Wind-Turbine-Models.com
NEG Micon 72C 1500	Wind-Turbine-Models.com
Nordex N70 – 1.5 MW	Wind-Turbine-Models.com
Nordex S70 1500kW	Technical specifications of the machine provided by equipment manufacturer
Nordex S77 1500kW	Technical specifications of the machine provided by equipment manufacturer
NEG Micon 82 1650	TheWindPower.net
Vestas V66-1650	TheWindPower.net
Vestas V82-1.65	Wind-Turbine-Models.com
Vestas V80-1.8	Wind-Turbine-Models.com
Vestas V90-1.8	Wind-Turbine-Models.com
Enercon E66 1870lW	Wind-Turbine-Models.com
DeWind D8(8.2)	Wind-Turbine-Models.com
Gamesa G80 2.0MW	Wind-Turbine-Models.com
Gamesa G83 -2.0MW	Wind-Turbine-Models.com
Gamesa G87 2.0MW	Wind-Turbine-Models.com
Gamesa G90 2.0 MW	Wind-Turbine-Models.com
Gamesa G97 2.0 MW	Wind-Turbine-Models.com
Vestas V80-2.0	Wind-Turbine-Models.com
Vestas V90-2.0	Wind-Turbine-Models.com
Senvion MM100 2mW	Wind-Turbine-Models.com

RePower MM 82	TheWindPower.net
RePower MM 92	TheWindPower.net
Nordex N90-2300	TheWindPower.net
Siemens SWT 2.3 MW-93	TheWindPower.net
Siemens SWT 2.3 MW-101m	Wind-Turbine-Models.com
Siemens SWT 2.3 MW-108m	TheWindPower.net
Bonus 82.4m 2.3MW	Wind-Turbine-Models.com
Enercon E82m 2300kW	TheWindPower.net
Furhlander FL 2500_100	Wind-Turbine-Models.com
Furhlander FL 2500_80	TheWindPower.net
Furhlander FL 2500_90	Wind-Turbine-Models.com
GE 2.5xl	TheWindPower.net
Nordex N100-2500	TheWindPower.net
Nordex N80-2500	TheWindPower.net
Nordex N90-2500 HS	TheWindPower.net
Nordex N90-2500 LS	Wind-Turbine-Models.com
Siemens SWT-3.0MW-101m	Wind-Turbine-Models.com
Senvion 3mW 122m	Wind-Turbine-Models.com
Vestas V90-3.0	Wind-Turbine-Models.com
Senvion 3.2mW 114m	Wind-Turbine-Models.com
Senvion 3.4mW 114,	Wind-Turbine-Models.com
Senvion 3.4mW 114m	Wind-Turbine-Models.com
General Electric GE 3.6sl 111m 3600kwn	Wind-Turbine-Models.com
Siemens 3.6 MW 120 m	Wind-Turbine-Models.com
Siemens SWT -3.6MW-107m	Wind-Turbine-Models.com
Areva Multibrid m5000	Wind-Turbine-Models.com
BARD 5.0	Wind-Turbine-Models.com
RePower 5M	TheWindPower.net
Senvion 6.2M152 offshore	Wind-Turbine-Models.com
Senvion 6.2M126 offshore	Wind-Turbine-Models.com
Vestas 164 8mW	Wind-Turbine-Models.com