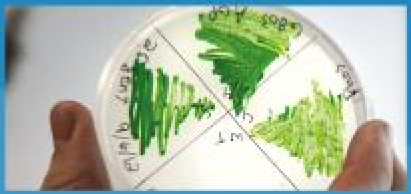



Projections of Distributed Photovoltaic Adoption in Kentucky through 2040

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NREL/PR-6A20-68656

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Foreword

The National Renewable Energy Laboratory (NREL) has developed a deep understanding of clean energy technologies and markets and has a long history of providing technical analysis and policy decision support to states. In order to respond to emerging state needs and help states understand the implications of state actions on advanced energy technology deployment, NREL conducts modeling and analysis of specific state-level energy policy actions.

The Solar Technical Assistance Team (STAT) Network is a project of the U.S. Department of Energy and is implemented by NREL. The purpose of STAT is to provide credible and timely information to policymakers and regulators for the purpose of solar technology-related decision support.

This analysis was conducted by the STAT Network at the request of the Kentucky Energy Office.

Project Description

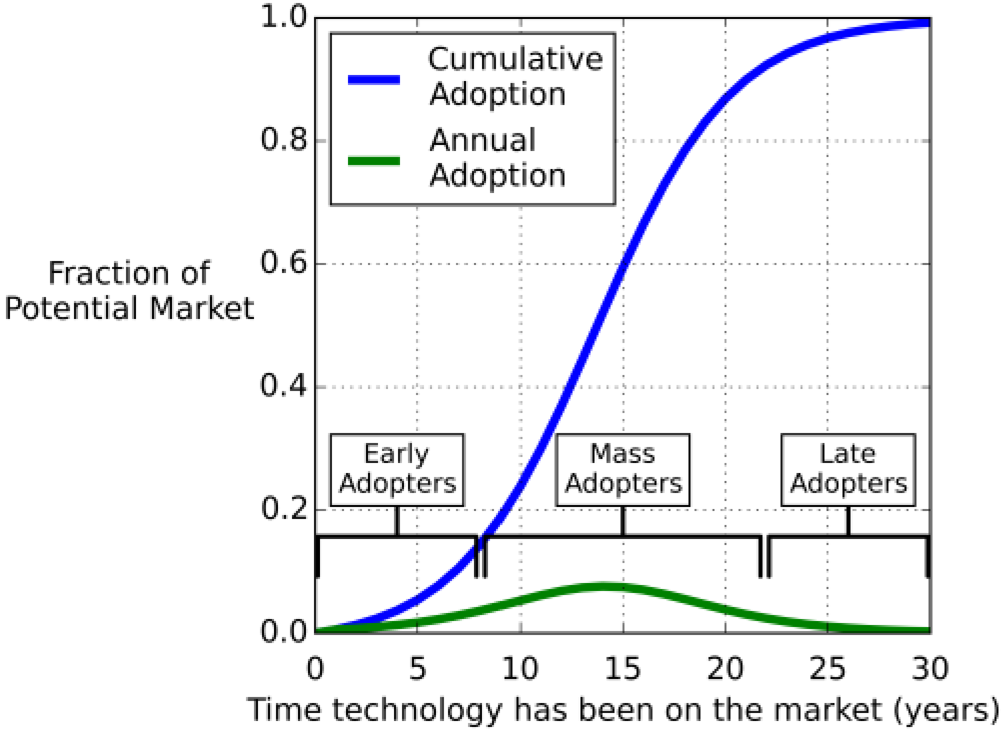
- NREL has used dGen (the Distributed Generation Market Demand Model) to project the adoption of distributed PV in Kentucky through 2040.

- This presentation gives a high-level overview of the model and the analysis results. For complete documentation of the model, see *The Distributed Generation Market Demand Model (dGen): Documentation* (Sigrin et al. 2016).

dGen Model Description

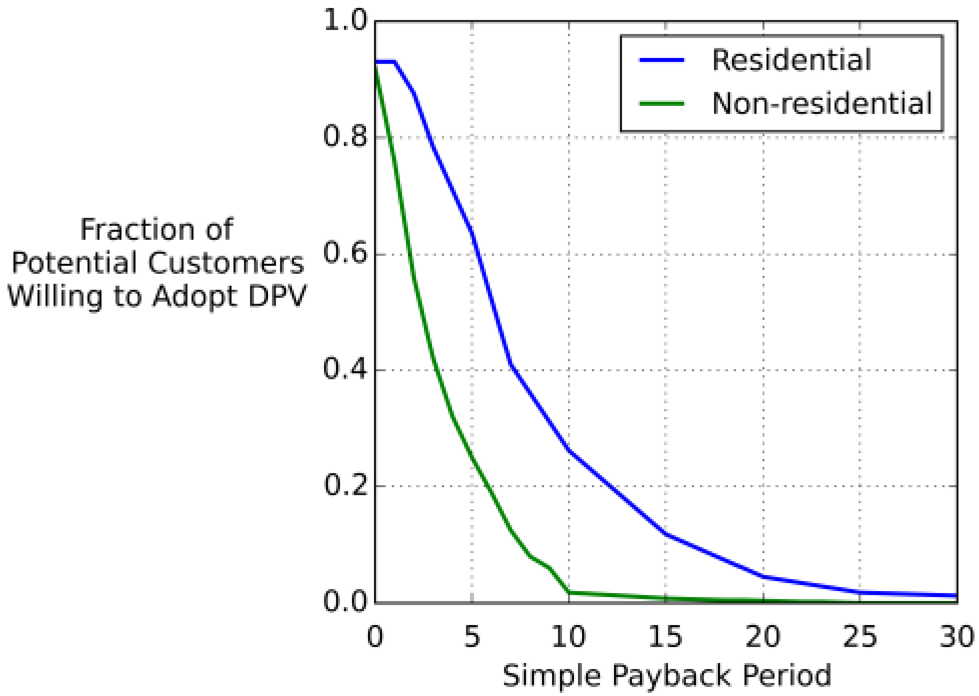
dGen Model Description

- The Distributed Generation Market Demand model (dGen) was developed by the National Renewable Energy Laboratory (NREL) as a tool to project the adoption of behind-the-meter PV in the continental United States.
- The framework captures commonly observed trends of how new technologies diffuse into a population with an "S-curve," as seen in the figure to the right.
- The curves shown are representative of the diffusion concept and are not the shapes used in this analysis.



dGen Model Description

- dSolar uses the curves shown to characterize the relationship between PV's economic attractiveness (payback period in years) and the fraction of a population that would be willing to purchase the technology.
  - *For example, with a 15-year payback, we predict 12% of possible residential customers and 1% of possible commercial and industrial customers would be willing to adopt solar PV.*
- These figures set the upper bound of the S-curve curve (in blue) of the previous slide. The model recalculates economic conditions for every two years in the forecast and adjusts the shape of the curve (and therefore the rate of diffusion) accordingly.
- This method reflects the fact that system cost is the primary driver of PV adoption while also capturing the non-economic considerations of customers.
  - *For example, even with long payback periods that would achieve lower rates of return than other potential investments, we would still expect a small percentage of possible customers to adopt PV. Conversely, even if the payback period is zero, we still would expect a small number of eligible customers to not adopt.*

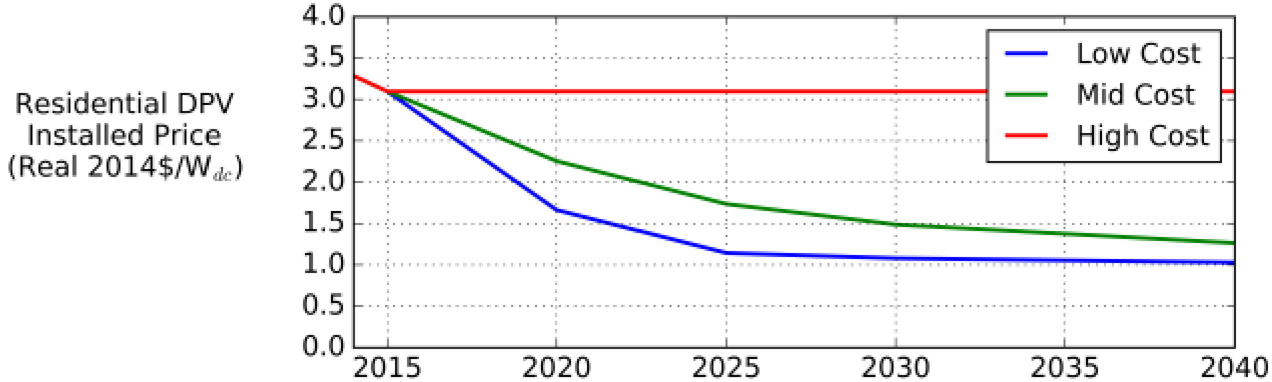


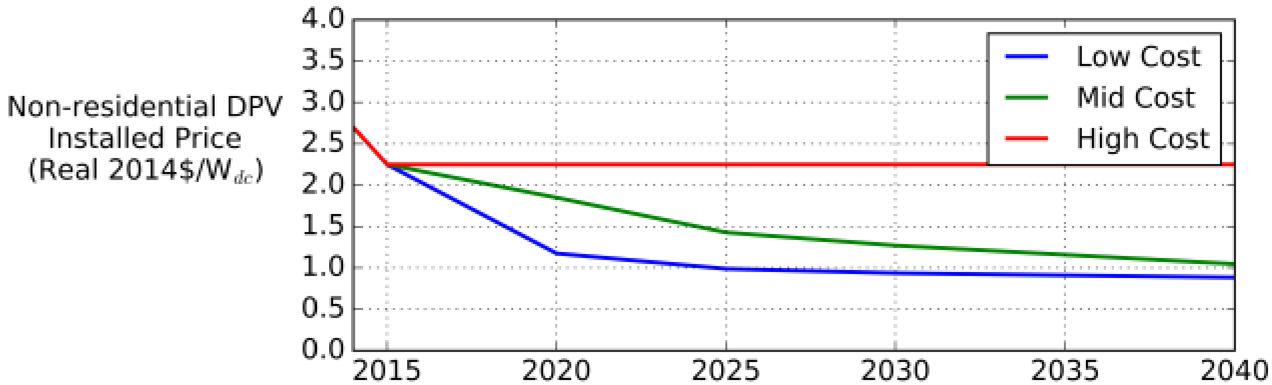
Source for Residential data: *Diffusion into New Markets: Economic Returns Required by Households to Adopt Rooftop Photovoltaics* (Sigrin and Drury 2014)
Source for Non-residential data: *Rooftop Photovoltaics Market Penetration Scenarios* (Paidipati et al. 2008)

Scenario Definition and Model Assumptions

Scenario Definition

This analysis includes three scenarios, projecting the adoption of distributed PV in Kentucky under three different possible trajectories that PV prices could take. Each scenario also varied the projected changes in the price of electricity to reflect the changes that would occur as the bulk power system evolved under harmonious technology costs. Future technology costs are obtained from NREL's 2016 Annual Technology Baseline (ATB) data set.[1] These scenarios do not necessarily capture the entire possible range of DPV adoption.



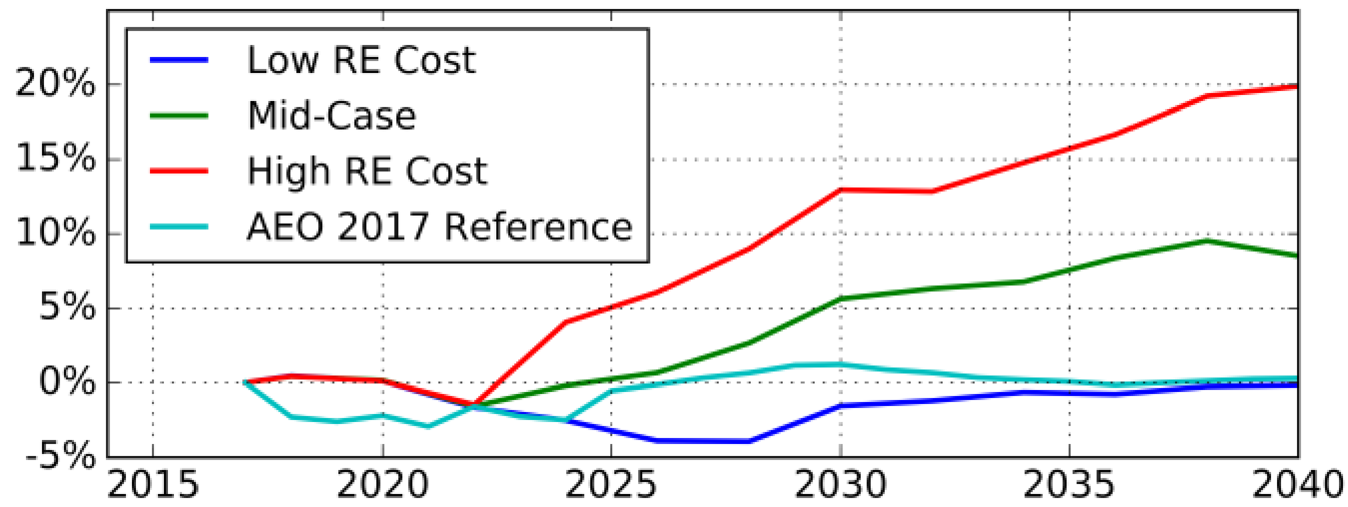


1. Actual modeled costs deviate slightly from these values on a county-by-county basis, according to a regional capital cost multiplier.

Electricity Prices

Electricity price changes were obtained from the "Low RE Cost," "Mid-case," and "High RE Cost" scenarios within NREL's 2016 Standard Scenario model runs. The reference case from the EIA's 2017 Annual Energy Outlook (AEO) is also provided for comparison.

Projected % Change in Retail Price of Electricity Relative to 2017



Fixed Assumptions

These assumptions were held constant across the three scenarios:

- Non-residential customers evaluate economics with a 40% down payment and finance the rest with a 20-year 8.0% loan (nominal terms).
- Through 2021, residential customers evaluate economics for a cash-purchased system. Starting in 2022, residential customers evaluate economics with a 40% down payment and finance the rest with a 20-year 8.0% loan (nominal terms).
- Adoption in the residential sector is restricted to owner-occupied detached buildings.
- Full retail net metering is assumed through the duration of the analysis. Current law obligates Kentucky's utilities to offer full-retail net metering—although if the cumulative generating capacity of net-metered systems reaches 1.0% of a utility's single hour peak load during the previous year, the Public Service Commission may limit the utility's obligation to offer net metering (Net Metering Interconnection Guidelines, Appendix A, Administrative Case No. 2008-00169). Given that the language sets a trigger for a review, but that the default is implied to be no action, NREL has assumed a continuation of current law. (*It is important to note that this is not an endorsement of any particular action, policy, or legislation.*)
- Five-year federal MACRS depreciation is available for non-residential customers. Residential customers do not depreciate systems.
- The federal investment tax credit is modeled according to law as of June 2017 (i.e., it phases down to 10% for non-residential customers and to 0% for residential customers by 2022).
- The maximum market share (which influences the rate of adoption) is based on the market-share-versus-payback curves shown on Slide 4.
- PV financial performance is evaluated based on retail tariffs in Kentucky as of May 2017. Current tariffs are scaled by projected changes in the total cost of electricity. Customers select the tariff that results in the lowest cost of electricity for them, of the tariffs they are allowed to subscribe to (e.g., minimum and maximum demand requirements are respected).
- The number of customers is assumed to scale with load growth projections for each sector from the AEO 2016 reference case for the East South Central region (EIA 2016).
- Historical DPV adoption trends in Kentucky were used to tune the P and Q parameters of the Bass diffusion model.

PV Technical Performance Assumptions

Characteristic	Value
System Size (Fixed)	Sized to provide 95% of annual consumption; constrained by available roof area
Module Type (Fixed)	Multicrystalline silicon
Module Power Density	160 W/m^2 in 2016, increasing to 220 W/m^2 by 2040
Tilt	Follows distribution of buildings characteristics in Kentucky observed in lidar data (Gagnon et. al. 2016)
Azimuth	Follows distribution of buildings characteristics in Kentucky observed in lidar data (Gagnon et. al. 2016)
Ground Coverage Ratio	0.7 for systems on flat roofs; for systems on tilted roofs, PV installed flush to roofs
Total System Electrical Losses (Fixed)	14%
Module Degradation (Fixed)	0.5%/year
Inverter Efficiency (Fixed)	96%
DC to AC Ratio (Fixed)	1.1

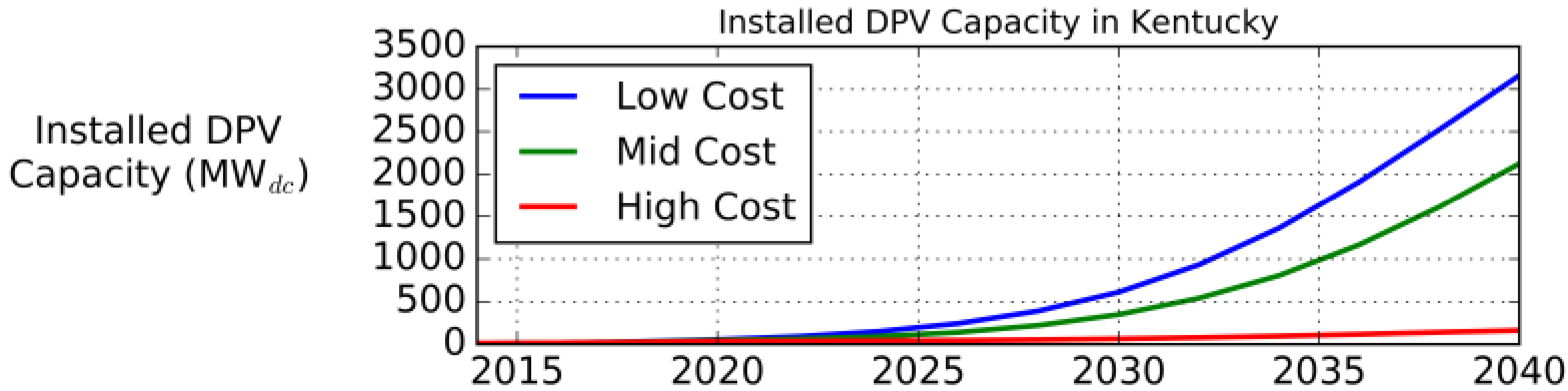
Kentucky Electric Utility Classification In Model

We report the results of this analysis for four administrative regions. The “Kentucky” results are for the entire state of Kentucky, including all utilities. The other three regions are aggregations of utilities, defined below.

A] LG&E / KU	1] Louisville Gas & Electric Company (LG&E) 2] Kentucky Utilities Company (KU)
B] Big Rivers Electric Corporation	1] Jackson Purchase Energy Corporation 2] Kenergy Corporation 3] Meade County RECC
C] East Kentucky Power Cooperative (EKPC)	1] Big Sandy RECC 2] Blue Grass Energy Cooperative 3] Clark Energy Cooperative 4] Cumberland Valley Electric 5] Farmers RECC 6] Fleming-Mason Energy Cooperative 7] Grayson RECC 8] Inter County Energy Cooperative 9] Jackson Energy Cooperative 10] Licking Valley RECC 11] Nolin RECC 12] Owen Electric Cooperative 13] Salt River Electric Cooperative 14] Shelby Energy Cooperative 15] South Kentucky RECC 16] Taylor County RECC

Results

Distributed PV Projections for Kentucky



Installed DPV Capacity in Kentucky (MW_{dc})

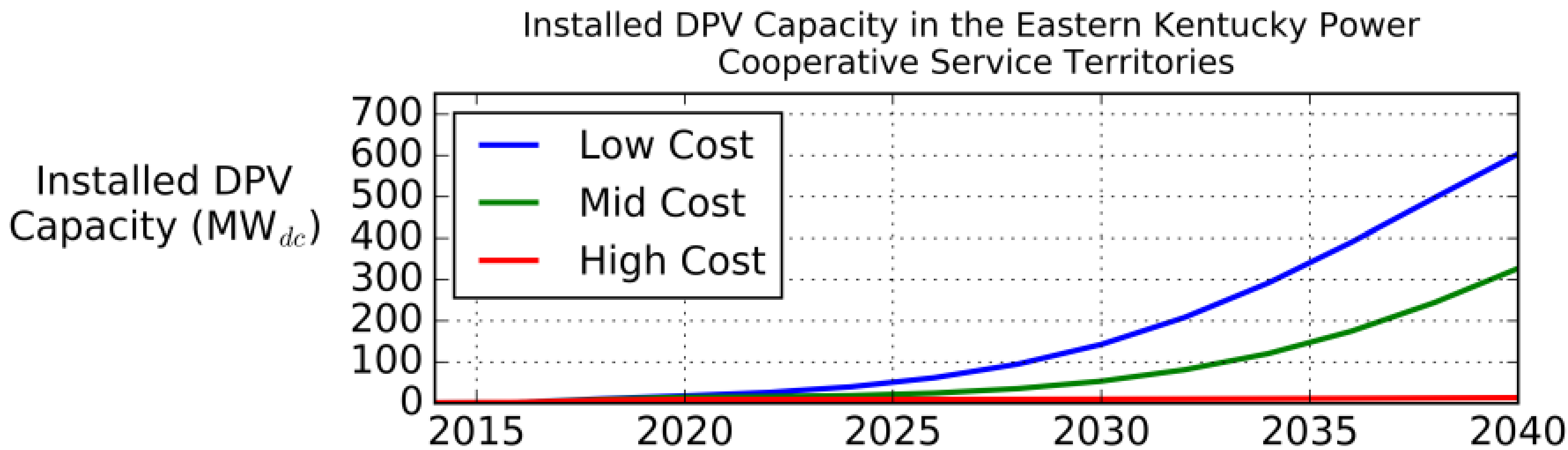
Kentucky	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Low Cost	12.0	15.6	30.2	54.6	90.2	149.1	242.9	390.3	610.6	932.0	1362.5	1907.1	2523.3	3160.0
Mid Cost	12.0	15.6	27.3	46.9	62.0	90.1	139.2	220.8	347.9	539.5	805.3	1166.9	1613.4	2124.2
High Cost	12.0	15.6	23.5	35.7	37.7	40.5	44.9	52.0	63.3	77.3	95.0	116.2	140.3	162.0

DPV Energy Generation in Kentucky (GWh_{ac}/year)

Kentucky	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Low Cost	15.5	20.1	39.2	70.8	117.0	193.5	315.4	506.8	793.0	1210.6	1770.3	2479.0	3281.5	4111.6
Mid Cost	15.5	20.1	35.5	61.0	80.9	117.9	182.5	289.5	456.2	707.5	1056.0	1529.7	2114.4	2782.4
High Cost	15.5	20.1	30.6	46.7	49.3	53.0	58.7	68.0	82.7	101.1	124.2	151.9	183.4	211.9

- Total projected DPV capacity in Kentucky ranges from 162 MW to 3,160 MW, depending on the future price of PV.
- There are 130 million square meters of roof area in Kentucky that are technically suitable for hosting PV systems, which equates to a technical potential of 18.0 GW (21.4 TWh/year) for rooftop PV (Gagnon et al. 2016). Therefore, the adoption levels in 2040 range from 1% to 18% of the technical potential of the state.

Distributed PV Projections for EKPC



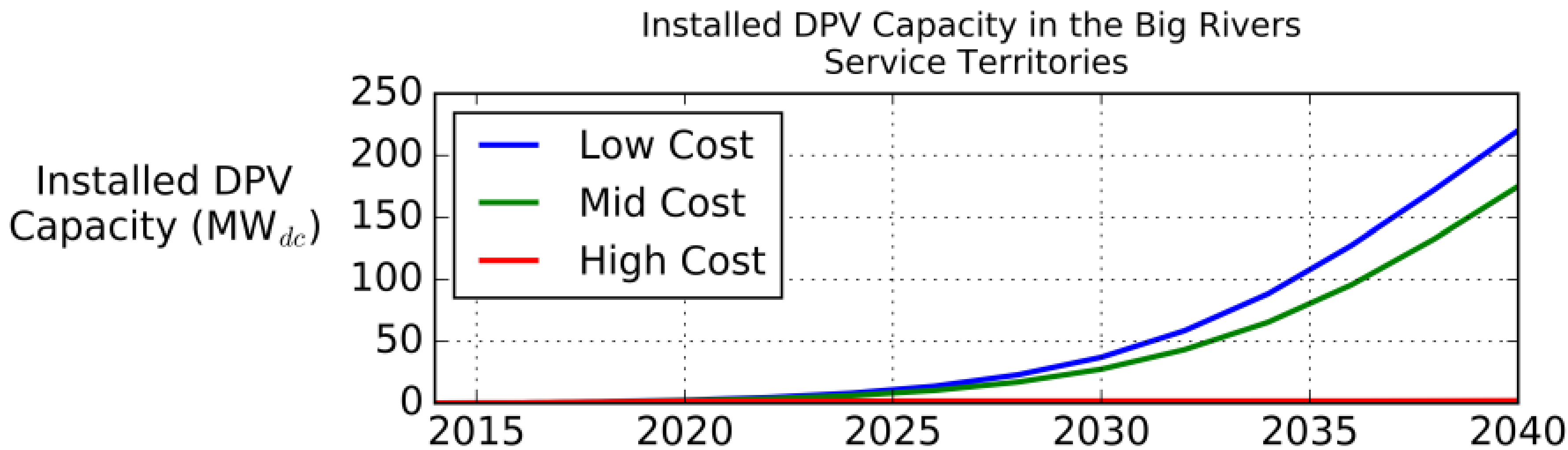
Installed DPV Capacity in the Eastern Kentucky Power Cooperative Service Territories (MW_{dc})

EKPC	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Low Cost	1.2	2.0	10.5	17.7	25.8	39.7	61.7	94.8	142.4	208.0	291.2	390.0	497.3	603.2
Mid Cost	1.2	2.0	9.1	14.5	15.8	18.4	24.3	35.3	53.4	81.0	120.0	174.4	244.2	326.9
High Cost	1.2	2.0	7.3	8.9	9.0	9.1	9.2	9.4	9.8	10.3	10.9	11.6	12.5	13.3

DPV Energy Generation in the Eastern Kentucky Power Cooperative Service Territories (GWh_{ac}/year)

EKPC	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Low Cost	1.5	2.5	13.7	23.1	33.7	51.9	80.8	123.9	186.2	271.9	380.6	509.7	650.0	788.4
Mid Cost	1.5	2.5	11.9	19.0	20.6	24.2	32.0	46.6	70.4	106.9	158.4	230.1	321.9	430.7
High Cost	1.5	2.5	9.5	11.7	11.8	11.9	12.1	12.3	12.8	13.4	14.2	15.2	16.3	17.4

Distributed PV Projections for Big Rivers



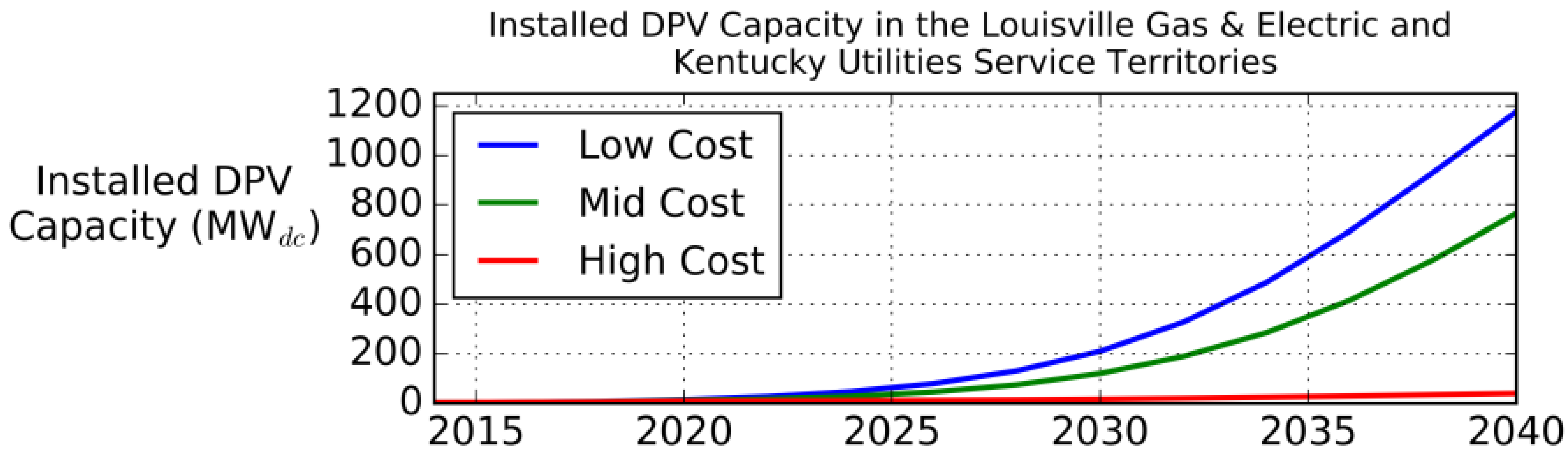
Installed DPV Capacity in the Big Rivers Service Territories (MW_{dc})

Big Rivers	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Low Cost	0.1	0.3	1.2	2.5	4.6	8.1	13.7	22.9	37.1	58.6	88.4	127.4	172.4	220.1
Mid Cost	0.1	0.3	1.1	2.2	3.7	6.2	10.3	17.1	27.5	43.3	65.4	95.6	132.8	174.9
High Cost	0.1	0.3	1.0	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.9	2.0

DPV Energy Generation in the Big Rivers Service Territories (GWh_{ac}/year)

Big Rivers	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Low Cost	0.1	0.4	1.6	3.2	5.9	10.4	17.7	29.7	48.1	75.9	114.5	165.1	223.6	285.5
Mid Cost	0.1	0.4	1.5	2.9	4.8	8.0	13.4	22.2	35.8	56.4	85.2	124.5	173.0	227.8
High Cost	0.1	0.4	1.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.5	2.7

Distributed PV Projections for LGE/KU



Installed DPV Capacity in the Louisville Gas & Electric and Kentucky Utilities Service Territories (MW$_{dc}$)

LGE/KU	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Low Cost	2.3	3.6	6.8	14.5	26.7	46.8	79.1	130.8	209.8	327.6	488.3	694.7	930.8	1176.7
Mid Cost	2.3	3.6	6.0	12.2	17.4	27.7	45.3	74.4	120.0	189.1	285.1	416.1	578.6	765.8
High Cost	2.3	3.6	5.0	9.5	9.9	10.7	11.8	13.6	16.3	19.7	24.0	29.1	34.7	39.8

DPV Energy Generation in the Louisville Gas & Electric and Kentucky Utilities Service Territories (GWh$_{ac}$/year)

LGE/KU	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Low Cost	3.0	4.6	8.7	18.7	34.5	60.6	102.4	169.5	271.9	424.8	633.7	902.5	1210.2	1531.2
Mid Cost	3.0	4.6	7.8	15.8	22.8	36.4	59.8	98.3	158.5	249.4	375.9	548.2	761.6	1006.9
High Cost	3.0	4.6	6.5	12.5	13.1	14.0	15.5	17.9	21.5	26.0	31.7	38.4	45.8	52.5

Appendix

History of NREL's State-Level Decision Support

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Nomenclature

AEO	Annual Energy Outlook
ATB	Annual Technology Baseline
dGen	Distributed Generation Market Demand Model
DPV	distributed photovoltaics
EKPC	Eastern Kentucky Power Cooperative
GWh_{ac}	gigawatt-hour (alternating current)
LGE	Louisville Gas and Electric Company
KU	Kentucky Utilities Company
MACRS	Modified Accelerated Cost Recovery System
MW	megawatt
MW_{dc}	megawatt (direct current)
NREL	National Renewable Energy Laboratory
RECC	Rural Electric Cooperative Corporation
STAT	Solar Technical Assistance Team
W/m^2	watts per square meter

Thank you!

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