June 2019

RE-Mixing our ENERGY FUTURE

WHAT DOES IT REALLY MEAN to go 100% renewable?

ProtoGen
ENERGY ALIGNED

WHITE PAPERS

COMMUNITIES ARE READY
FOR 100% RENEWABLE ENERGY

How do we get there?

Communities are pushing for a renewable energy transition, bringing new voices to the conversation. These voices have the power to shape a political outcome but success will require aligning highly complex technology, economics and regulatory knowledge sets. Tools and resources are needed to educate, build capacity, and promote collaboration among community members and leadership.

This is the ultimate purpose of RE-Mixer – a free Excel-based renewable energy planning tool developed by ProtoGen. Below we introduce the tool and demonstrate it by mapping a transition to 100% renewable energy in Southeastern PA.

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Introduction

In September 2017 Phoenixville became Pennsylvania's first municipality to pass a Ready for 100 resolution. Sixteen more Southeastern-PA municipalities (and counting) have since made the commitment, bringing the nation's total to 121. The resolution language typically sets targets of 100% renewable energy for electricity by 2035 and for all other requirements (think heat and transportation) by 2050, and calls for the creation of a supporting plan. The commitments are the result of a grassroots campaign organized by the Sierra Club.

Ready for 100 brings into a focus a political path forward in which communities set the terms of an energy transition and become the increments of change. A community-focused approach will promote equitable distribution of the economic and environmental benefits among local users and generators of energy.

From a practical perspective, communities powered by 100% renewable energy (RE) may likely look very different than they do today: solar accounted for less than a quarter of a percent of electricity generated in PA last year, and more than 80% of that was from small, distributed systems such as rooftop PV.

READY FOR 100%

Ready for 100 goals form the upper boundary of a renewable energy transition, but how does the transition from here to there actually play out? This was the subject of a talk we recently gave at a meeting sponsored by the Chester County Economic Development Council.

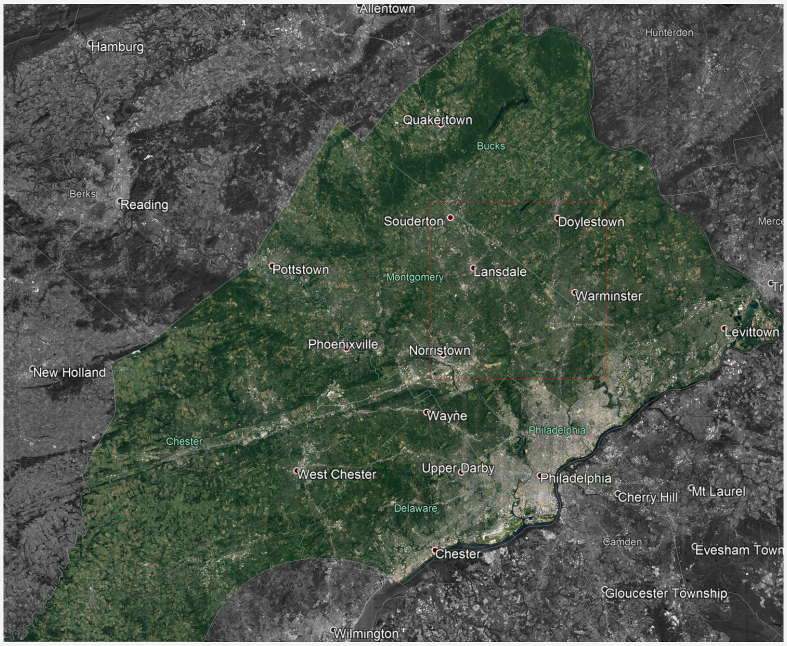
We built a simple tool to calculate the amount of solar needed to completely offset the county's annual electricity usage. While presenting our findings, it became evident that there's a real need to make energy transition planning more accessible for community stakeholders. Over the ensuing weeks, RE-Mixer was born.

Introduction
(cont.)

RE-Mixer is an Excel-based renewable energy planning tool. Unlike sophisticated engineering tools or black-box proprietary policy modeling suites, RE-Mixer serves as a point of entry for audiences looking to understand the relative scale and scope of the renewable energy transition. It allows for an iterative review, analysis and projection of energy demand and renewable energy sources over a user-specified period of years, and outputs information about the corresponding renewable energy capacity requirements, costs, land use, and greenhouse gas (GHG) reductions.

The tool is pre-populated with 2018 data from the Energy Information Administration (EIA) on electricity generation fuel sources by state and 2015 data from the Delaware Valley Regional Planning Commission (DVRPC) on municipal-level electrical energy demand for nine Delaware Valley counties. Users can select from these data or input their own. The model inputs are pre-populated with assumptions based on research and industry resources which we've made available via this link.

To kick off the conversation, we used RE-Mixer to map a 2020-2050 transition scenario for Southeastern PA's five-county region (Bucks, Chester, Delaware, Montgomery and Philadelphia).



Southeastern PA Analysis

***In this section we use RE-Mixer** to analyze one possible technological pathway to 100% renewable energy in the five-county Southeast Pennsylvania region.*

The table provides some basic data about population, land area, and energy demand. A calculation of energy demand density is also provided showing total annual energy use per square mile.

Unsurprisingly, Philadelphia has by far the highest density of energy demand, while Chester and Bucks Counties are lower by an order of magnitude. This sets up a conversation in which surrounding counties become net exporters to the City.

County	Pop.	% total	mi²	% total	MWh (2015)	% total	MWh/mi²
Bucks	627,367	15%	622	28%	6,168,280	16%	9,917
Chester	515,939	13%	760	34%	6,110,010	16%	8,039
Delaware	563,894	14%	191	9%	4,956,308	13%	25,949
Montgomery	819,264	20%	487	22%	8,134,605	21%	16,704
Philadelphia	1,567,443	38%	143	6%	13,515,709	35%	94,515
Total	**9,194,093907**		**2,203**		**38,884,913**		

Energy is sold to homes or business by the kilowatt-hour (kWh), equivalent to a thousand Watts-per-hour. To begin thinking about replacing non-renewable energy sources, we need to talk in Megawatt-hours (MWh), equavalent to a thousand kWh. The five-county area's 2015 energy demand was about 39 million MWh/yr. Southeastern PA's seventeen RF100 communites represent about 8% of that total.

Note: electrical power is measured in Watts; energy is power over time (i.e. Watt-hours).

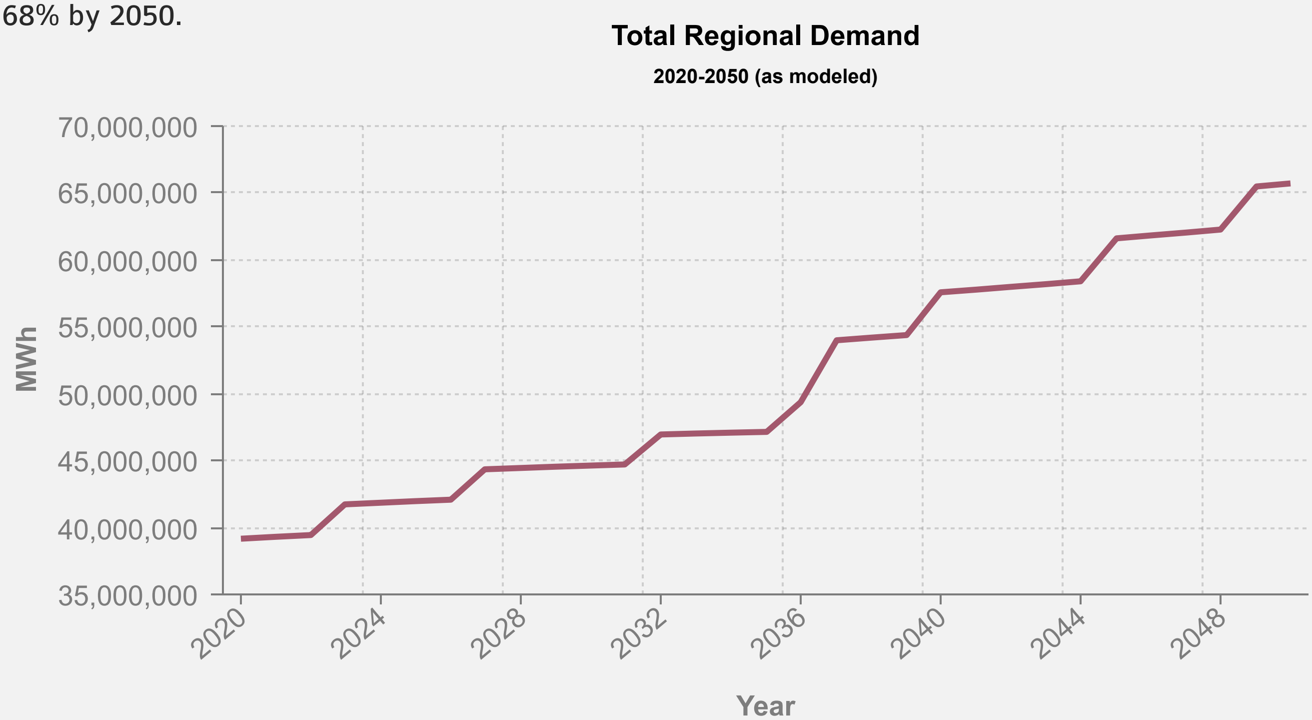
Model Input:
Energy Demand

***In the Energy Demand input section** we define the electricity load for analysis, including major contributing factors, and model how these will change over time.*

Energy demand will be influenced by many factors over the thirty-year transition period. The RF100 goals are centered around electrification of everything including transportation and building heating as well as industrial processes. These are captured by "EV charging" and "All other new demands" inputs. The "Efficiency Savings" input accounts for the expected overall reduction of annual energy consumption due to energy efficiency measures, while "Marginal Reserve" reflects generation that must be built above the actual need to establish operating reserves.

Energy storage systems will be critical to the renewable energy transition to balance out the intermittency of demand (think peaking loads) and renewable energy sources (think passing clouds), and for shifting the excess energy generated during times of peak production (i.e. midday) to times of peak consumption and/or no sun (i.e. evenings). Battery capacity is sized as a percentage of new renewable energy built; the "Efficiency Loss" input captures the charge/discharge inefficiency of electro-chemical energy storage such as lithium-ion. We note that other kinds of energy storage such as pumped hydro and thermal storage will also be necessary, but are not specifically named in the tool.

Netting out these estimated energy demand additions and savings (and not correcting for population growth/degrowth), the model returns a 2050 need of around 66 million MWh/yr, or an increase of 68% by 2050.

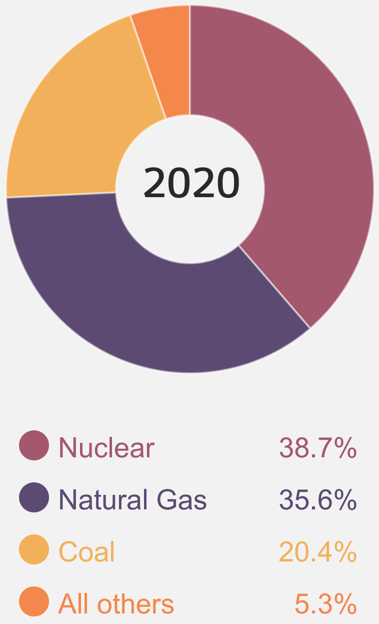


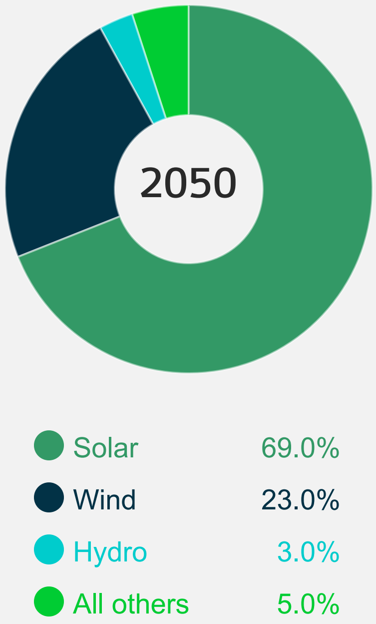
Model Input:
Generation Mix

***In the Generation Mix input section** we select a state-specific beginning electricity generation mix, and defines a renewable energy mix to be to be achieved over a period of n years.*

Electric power generation in Pennsylvania was powered by ten different fuel types last year. To keep our analysis simple, this was assumed as the beginning energy mix. Of those, three (nuclear, natural gas and coal) met 95% of energy needs, while utility-scale solar met less than one-half of one percent. This data does not reflect behind-the-meter PV systems such as those on residential or commercial rooftops.

Pulling from a recent research co-authored by LUT University and Energy Watch Group, we arrived at a new mix for 2050. Utility-scale PV leads the mix at 69% with wind at 23%; hydro, combustion (e.g. landfill gas, hydrogen), and other renewable energy (RE) sources (rooftop PV, in this case) round out the generation mix. These are supported by battery energy storage systems. The battery energy storage requirement was estimated at 23% of the total RE capacity built.





Capacity factors for Other Combustion, Conventional Hydro, and Geothermal are input in this section; those for Solar and Wind, and other RE are derived in the next section. Capacity factor is a unitless ratio expressing the actual electrical energy output of a generation source relative to its theoretical maximum output:

$$\text{Capacity factor} = \frac{\text{Annual Energy Production in MWh}}{\text{Generating Capacity in MW} \times 24 \times 365}$$

Model Input:
Renewable Energy Sources

***In the Renewable Energy Sources input section** we fine-tune RE production values according to local conditions or other considerations.*

PV system output is geographically dependent (L.A. has more hours of sunlight per year than Boston), and wind energy is even more so. In this section, we fine-tune renewable energy (RE) production values according to local conditions. The "Production" input allows the user to input local PV energy yield, which can be easily derived using NREL's PVWatts tool. "Local PV farm size" is used to calculate the area of PV developed in acres and square miles. We input the specs of a site we manage in Chester County. The user can select from one of four pre-selected wind turbines and seven different proxy sites to understand the impact of technology and wind resource on energy production. In addition to these, the user can input "Other RE". Selecting "Simple mode" from the drop-down allows the user to input a capacity factor directly. In "Blended Calc" mode, capacity factor is pulled from the "Other RE" tab.

Results

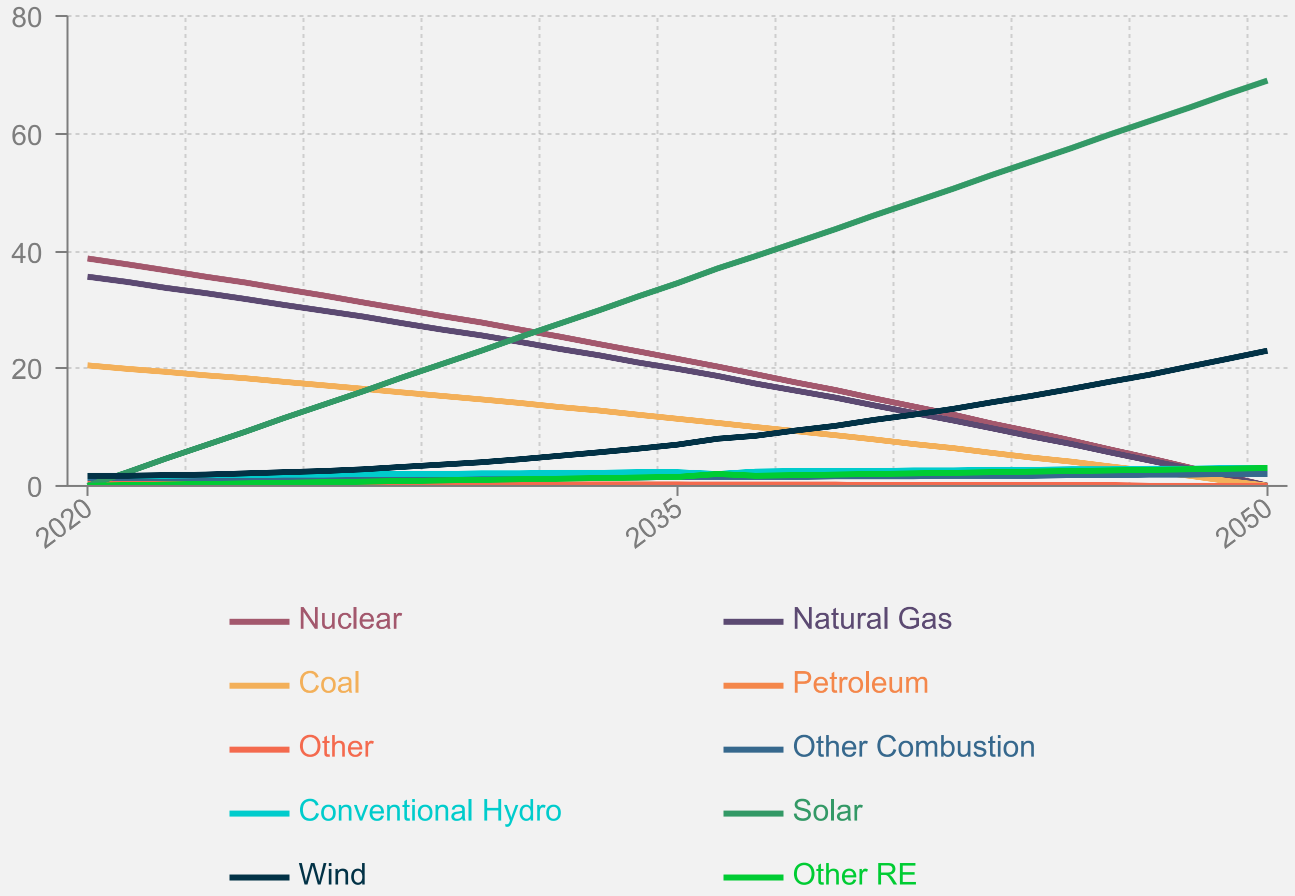
Combining total electrical demand with the percentage-share and capacity factor of each renewable energy source, we are able to back-into the amount of renewable energy needed to meet the goal by the ending date. These results are in the table to the right. Battery energy storage is shown separately from renewable energy generation.

	MW	Cost (2019$)
Non-fossil combustion	294	205,536,083
Conventional hydro	500	352,974,779
PV (grid-scale)	34,880	27,348,980,466
Wind	2,965	3,617,229,369
Other renewable energy	1,664	3,577,212,882
Subtotal: RE	**40,283**	**35,101,933,579**
Battery energy storage	9,265	1,725,048,229
TOTAL ENERGY:	**49,548**	**36,826,981,808**

The calculated cost to build the scenario modeled is approximately $37 billion (2019$), or about 13% of the estimated $290 billion that would otherwise be spent on energy over the same period (including all sources of Residential, Commercial & Industrial, and Mobile-Highway). It is noted that no allowance has been made for transmission and distribution upgrades or for decommissioning of existing non-renewable assets.

Results
(cont.)

The figure below shows the transition in electric generation fuel source and associated reduction in greenhouse gases (GHG). The non-renewable energy sources ramp down smoothly over the period; this is because the tool calculates the roll-off of non-renewable energy as a function of renewable energy growth. In reality the generating capacity of a single coal or nuclear plant is hundreds to thousands of MW, meaning the percentage of non-RE sources may drop off in fewer, larger increments.

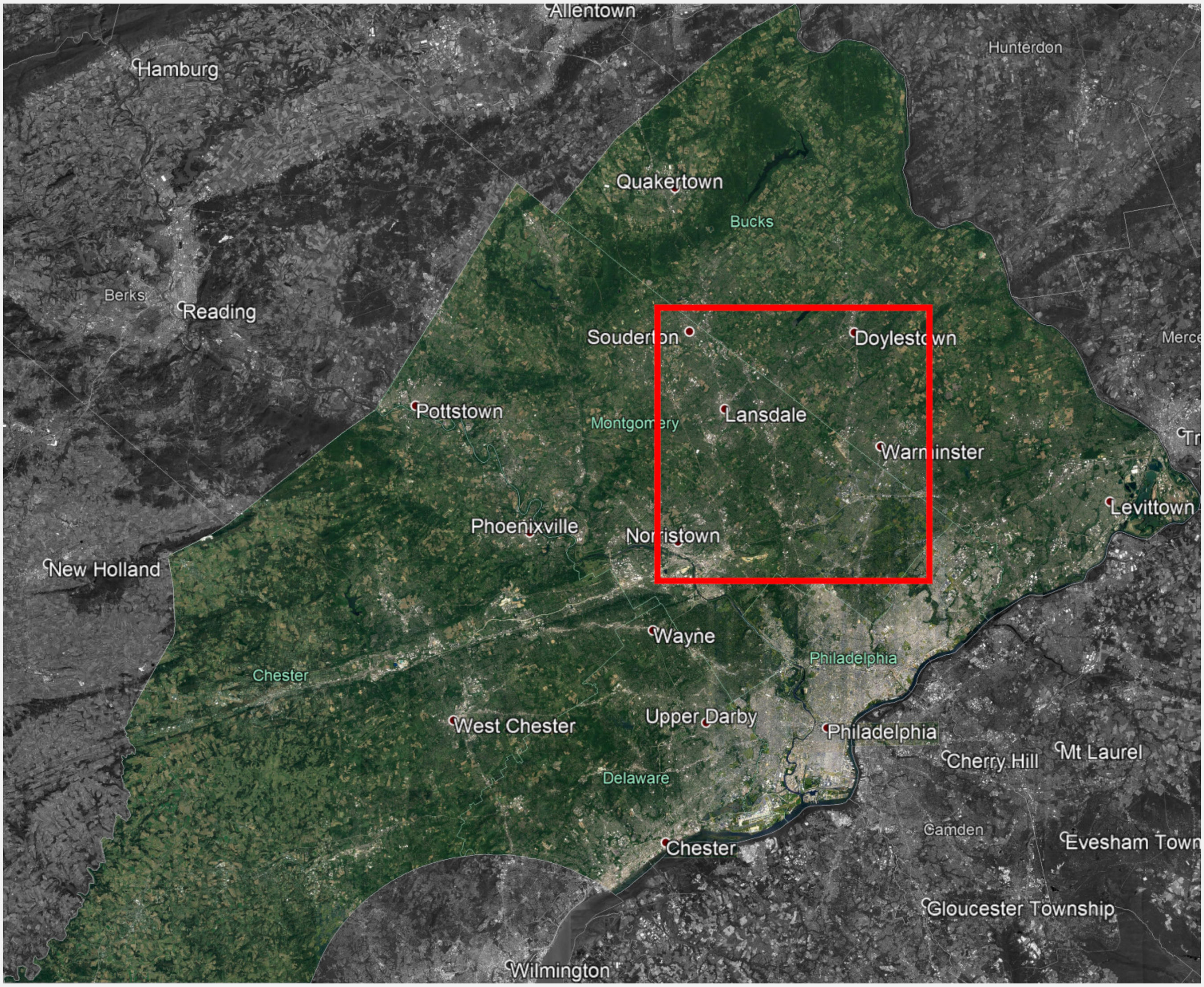


"We need to change the conversation: A transition to a global 100% renewable energy system is no longer a matter of technical feasibility or economic viability, but one of political will. Not only do we need ambitious targets, but also stable, long-term, and reliable policy frameworks, adapted to regional conditions and environments."

Hans-Josef Fell, "Global Energy System Based on 100% Renewable Energy" (2019)

Results
(cont.)

Another way to think about the big renewable energy contributors (solar and wind, in this case) is land area needed. The calculated requirement of 34,879 MW of grid-scale PV translates to an area of 284 miles²—12.89% of the total five-county area, or 17 x 17 miles as shown below. For reference, SEIA places Pennsylvania solar installed at 420.19 MW through Q4 2018, meaning that 83 times as much solar as currently exists in the Commonwealth will need to be built for the five-county area.



Results
(cont.)

Wind is likely more challenging to build locally than solar. The modeled wind power requirement of 2,965 MW corresponds to (706) 4.2-MW wind turbines—roughly twice the 1,369 MW currently installed in PA according to AWEA (although close to the 726 turbines currently installed, which are much smaller on average). The towers used in our model are 100 meters tall with rotors 150-m in diameter, for a tip height of 175m (574 feet).

Projects of this scale create a much higher level of complexity than grid-connected PV, and it may well be that the 30-year timeline is insufficient to lease property, pass local zoning, and overcome NIMBY-type objections. From this perspective, we would want energy mappers/planners to understand why offshore wind turbines, which are 3-5x bigger, start to make a lot of sense. (If you're curious check out GE's 12-MW Haliade-X).

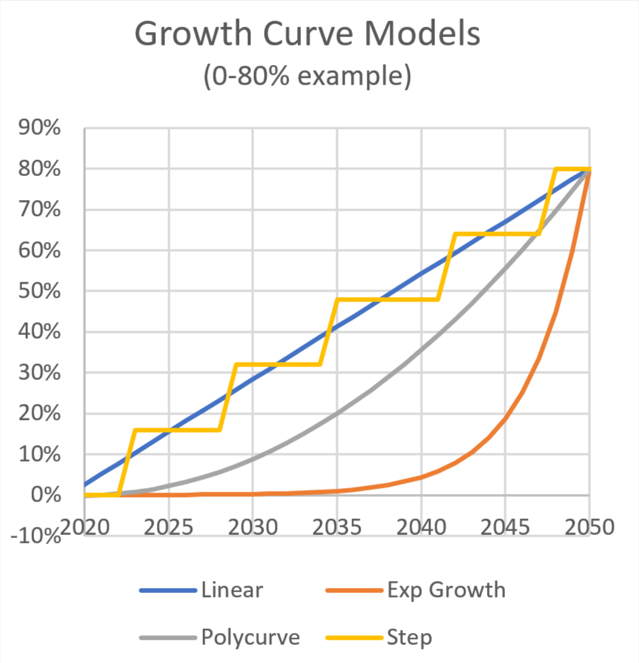
Caution: Curves Ahead

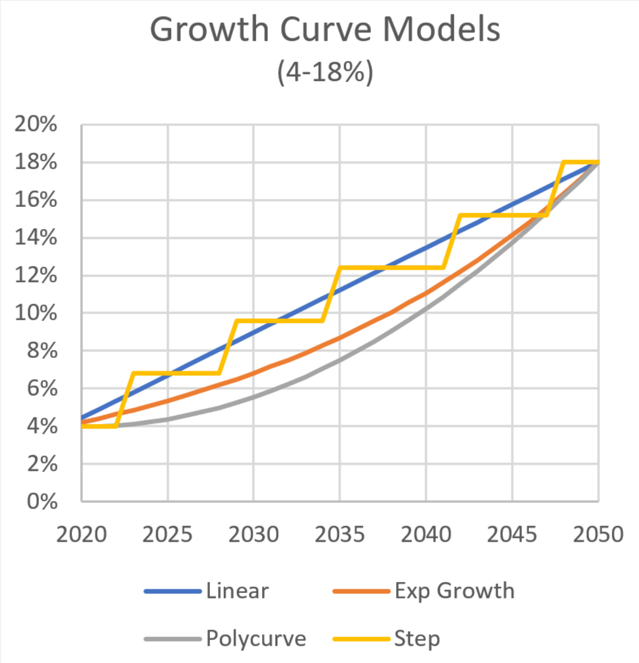
Now that we've established the scale and general scope of the transition scenario, how do you navigate a 30-year, $37 billion negotiation between stakeholders? The first step is to develop a common understanding of where there is flexibility to be had.

To that end, RE-Mixer allows the user to account for learning and experience curve effects by plotting energy demand, generation, and storage characteristics against one of four different growth or cost curves:

- **Linear** represents the shortest distance between two points, i.e. a straight line;
- **Exponential growth** curves compensate for a slow start with strong finish, allowing for investment dollars to benefit from least expensive technology cost (noted, however, that waiting until the last minute is also risky);
- **Polycurve** can be thought of as a gentle curve, i.e. the best of exponential and linear: balancing risk and financial returns of future investments;
- **Step** curves allows for plots that align well with policy goal setting, i.e. the number and duration of steps could correspond to municipal or state policy goal-tracking targets.

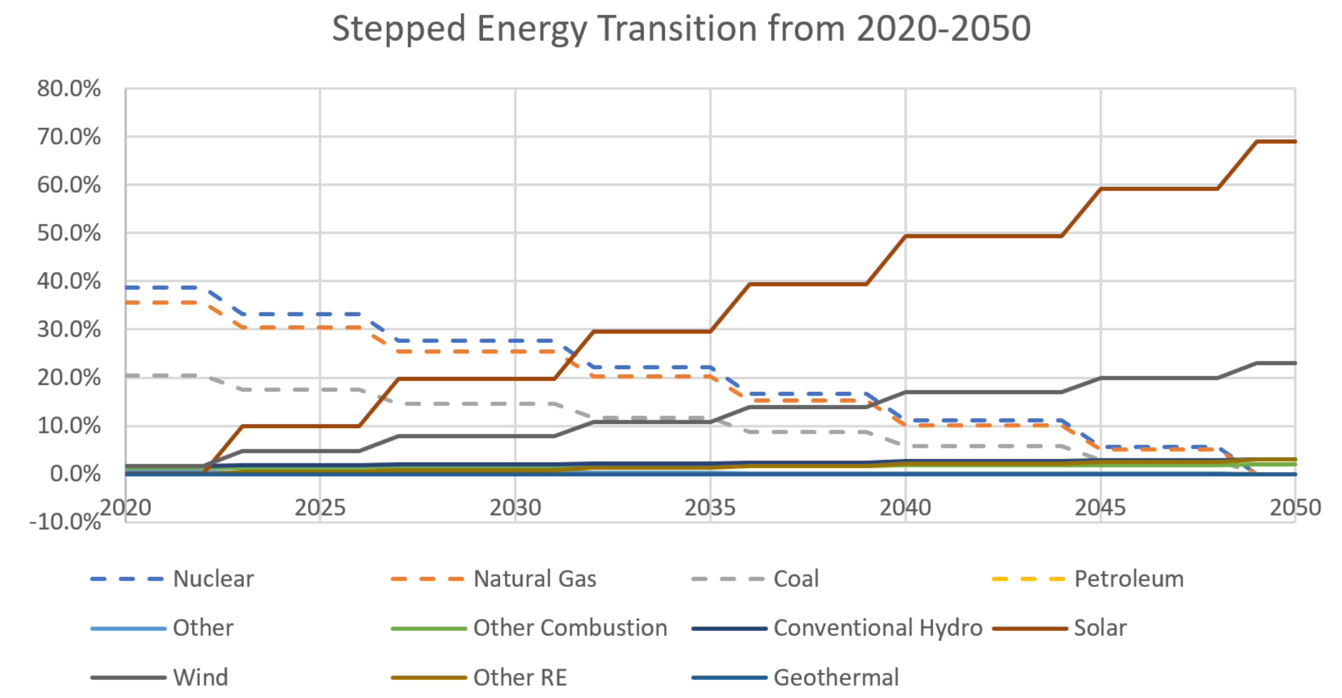
As shown below, the curves take on different forms depending on the target transition and timeline. The scenario considered here is most like the 0-80% example; however, we note that the "secret sauce" to any successful transition plan will be in the blending of local and regional curves and the incorporation of many viewpoints.





Caution: Curves Ahead
(cont.)

As a final thought exercise, we used step curves to demonstrate the allocation of 14-15% of total regional energy spending (including residential, commercial and industrial and mobile-highway) toward the renewable energy generation and storage targets. Seven investment periods of 4-5 years-each are shown over the 2020-2050 timeframe. It is noted that 4-5 year increments would comply with PJM's 3-year planning horizon and provide a little cushion for momentum to build. The scenario is shown in the graph below.



Conclusion

The most interesting part of this exercise was sizing the renewable generation and battery storage investments against existing energy spending. At first blush, fourteen percent of total energy spend doesn't seem insurmountable—especially given that the technologies evaluated are only going to become more cost-competitive in both absolute and relative terms. However, continued delay will only make the eventual climb more difficult. From this perspective, building momentum is critical.

Building and demonstrating RE-Mixer has also reinforced that energy is a very complex subject, to say nothing of undertaking a wholesale transition to 100% renewable energy sources. For more than 100 years, energy has made sense as a highly regulated "natural monopoly." By declaring their renewable energy intentions publicly, communities are collectively initiating a conversation about the future of the grid.

Conclusion
(cont.)

There are endless possible combinations of technologies to complete the transition, but as of today, most communities have limited options to address energy mix directly. New market structures must be created to accommodate community energy aspirations, and a competent workforce must be built out for the design, installation, operation, and maintenance of renewable energy systems.

RE-Mixer is not intended to provide the answers to this complex and multidimensional puzzle, but rather to build the capacity among community leaders and stakeholders to understand the scale and scope of the challenge and to facilitate conversations about the pieces on the board and how they ought to move.

One such move may be to develop an RFP or issue a request for a plan to be developed. ProtoGen is the ideal partner—based in PA but working regionally to align our economy through energy, mobility and communications planning. Leverage our vision and our team to achieve a successful energy transition.

About ProtoGen

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