Potential for Municipal Procurement Of Renewable Energy Via Virtual Power Purchase Agreements

EEDS Capstone Course

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Executive Summary

The following report details findings and results of research conducted by our group in response to the City of Columbus' RFP related to virtual power purchase agreements (VPPAs). The objective of our research was to determine whether or not a VPPA would be a viable method for Columbus to procure renewable energy as the city attempts to reduce its dependence on fossil fuels. The first objective of our research was to differentiate virtual power purchase agreements from physical power purchase agreements (PPPAs), which are the two most common forms of a power purchase agreement (PPA). In order to learn about the applicability of VPPAs in different scenarios, we reviewed a variety of case studies. We also used datasets obtained from the U.S. Energy Information Administration to derive market correlation of on-peak electricity prices in each major regional transmission organization (RTO) to the PJM West market in order to determine suitable locations for Columbus to enter a VPPA. Finally, we used contract price data obtained from the Intercontinental Exchange to learn about the average historical cost of wind PPAs, and the average historical and projected cost of solar PPAs.

Our findings suggest that VPPAs are extremely effective for corporations with facilities located in different grids spread across the country. Anheuser-Busch for example, has formed a VPPA with Enel Green Power which helped them achieve 100% renewable energy this year *(Big Game, 2019)*. Unfortunately, there is very limited data and information related to municipal application of these agreements. We did find other cities seeking information related to VPPAs such as the City of Boston (Multi City

Renewable Energy Request, n.d.)[1]. We also found VPPAs provide an opportunity to purchase renewables in regions where renewables may be less expensive owing to better underlying regional economics (e.g. wind in Texas or solar in Arizona). For these reasons, our recommendation is that Columbus continues to research VPPAs as well as other market-based agreements and potential for local procurement projects in order to make a choice that suits its short and long-term objectives. We have provided resources in this report that should be useful in this endeavor.

Introduction

The following report was produced by a group of students at The Ohio State University as part of their capstone course. Our research was conducted in order to assist the City of Columbus in their decision making process as it related to the procurement of renewable energy. Specifically, we researched the viability of virtual power purchase agreements for Columbus to potentially add a source of green energy to their grid. General power purchase agreements (PPAs) are market-based agreements that have become instrumental in many municipal, corporate, and community renewable energy procurement plans. Our primary objective was to research and differentiate virtual power purchase agreements (VPPAs) from physical power purchase agreements (PPPAs).

This report is designed to assist the City of Columbus in its mission to increase the quantity of energy procured via renewable energy projects. In addition to our primary objective, we also researched the regulatory and institutional barriers, benefits,

[1] See the link in the appendix for a list of municipalities interested in large scale renewable energy purchase

and case studies of VPPAs. We also conducted an analysis of the different energy markets to determine which locations would be best suited for Columbus to negotiate virtual power purchase agreements, along with an analysis of the development of the PPA market in recent years, which included a projected future outlook. Each of these segments are intended to inform the City of Columbus of its options as decisions are made to bolster its renewable energy portfolio.

Through our research, we have concluded the City of Columbus should look further into the potential use of VPPAs, however further research should be conducted. We suggest a procedure similar to the one used by Cummins Incorporated be implemented, as different intended outcomes call for different means of procurement. The case study on Cummins exemplifies how the City should analyze and identify its renewable options in the most sustainable and economic manner possible. Additionally, we suggest the city seek consultation with an individual or organization with experience negotiating these agreements. The complexity of VPPAs make them difficult to navigate without expert knowledge and experience, and much like regular PPAs there is a risk the City could overpay significantly for renewable energy.

Methods

The objective of our research was to provide the City of Columbus an in depth explanation of what a VPPA is, and how they are used. We did this by conducting a literature review of case studies, research papers, and news articles in order to differentiate PPAs from VPPAs. We then analyzed historical on-peak wholesale electricity prices from 2014 to 2017 for each of the United States' major energy markets

in order to determine which markets have been most correlated to Columbus' market, PJM West. This data is relevant to our research because we found that the economic effectiveness of a VPPA is directly correlated to how well the purchaser's market correlates with the generators market. We also conducted an analysis of historical PPA prices in order to help determine the direction of renewable PPA prices in the near future.

Data & Means of Collection

Wholesale electricity price data in all U.S. market hubs from 2014 to 2018 were collected. The hubs included in our analysis were ERCOT North, Indiana Hub, Mass Hub, Mic-C, NP-15, Palo Verde, SP-15, and PJM West, which is Columbus' market region (see the map in the appendix). Specific price data included high and low daily on-peak prices during this time period. Location of price hub, date of sale, high price for period, and low price for period are a few of the data points provided for all U.S. hubs. This price data was retrieved from the US. Energy Information Administration's (EIA) website and can be viewed in Table 1 below. It should be noted that the frequency of reported data for each region was at times inconsistent. Specifically, a portion of the data for the ERCOT North was unavailable for the end of 2018. For this reason we excluded the corresponding data for the rest of the regions in our analyses. Average PPA price data for both solar and wind projects were also used in one of our analyses. Solar PPA prices were collected from 2006 to 2017 and wind PPA prices were collected from 2008 to 2017. This data was retrieved from the Intercontinental Exchange's website.

Table 1: Average On-Peak Market Price Correlation (U.S Energy Information Administration)

Average On-Peak Market Price Correlation (2014-2018)					
Market	Average	Min	Max	StDev	Correlation w/ PJM
ERCOT North 345KV Peak	$31.18	$27.16	$41.57	5.95	0.385
Indiana Hub RT Peak	$39.28	$34.34	$48.67	5.99	0.686
Mid C Peak	$30.33	$23.04	$38.82	7.31	0.179
Nepool MH DA LMP Peak	$50.02	$35.57	$76.25	15.93	0.847
NP15 EZ Gen DA LMP Peak	$48.75	$33.53	$78.21	18.12	0.068
Palo Verde Peak	$34.09	$25.55	$42.48	8.10	0.191
PJM WH Real Time Peak	$43.59	$34.54	$63.55	11.82	N/A
SP15 EZ Gen DA LMP Peak	$41.42	$30.85	$52.22	9.69	0.281
Average of All RTOs	$39.41	$30.31	$52.32	8.93	0.776

Origional data from Table 1 sourced from the Intercontinental Exchange, and retrieved from U.S. EIA (U.S Energy Information Administration). ***See Figure 5 in the appendix for a map of U.S. RTO/ISO locations.***

Data Analysis

Using the daily on-peak wholesale electricity price data, we calculated average monthly price, average monthly minimum price, average monthly maximum price, and standard deviation of the monthly price for each of the hubs. This provided insight as to which markets were on average most similar to Columbus' regional market (PJM West) during the 2014-2018 time period. We then used the monthly averages to calculate the correlation of the markets to the PJM West market. The higher the correlation of the market to PJM-West, the lower the price risk of a VPPA contract from that region for the City of Columbus. It should be noted that there were a few potentially erroneous entries

that were removed from the EIA dataset, and further analyses should be conducted to confirm our findings.

The data for the price of solar and wind PPAs was used to generate graphs depicting historical and projected trends. This allowed us to estimate approximately what the city might end up paying to enter a PPA. It was unclear whether the data was for purely physical power purchase agreements, or if it was a mixture of physical and virtual power purchase agreements. As a result, we suggest further research be conducted to confirm these findings as well.

Differentiation

Today, there are several types of market-based mechanisms that can be used to procure renewable energy. One of these methods is known as a power purchase agreement (PPA). These agreements are popular among all types of businesses, organizations, and municipalities striving to bolster their renewable energy portfolios. A PPA is a general term for an agreement in which an entity agrees to pay a fixed price for electricity generated off-site. In the case of a PPA, the entity receives renewable energy certificates (RECs) which can then be used to meet state renewable energy standards or individual renewable goals *(Kent, n.d.)*.

There are two primary types of PPAs. The first and more common type is known as a physical power purchase agreement or a PPPA. This type of agreement is common across not only the United States, but also many other parts of the world. They are a very effective means of achieving renewable energy objectives in an economically efficient manner, so long as the negotiated agreement is carefully constructed

(Innovation in Power Purchase Agreement Structures, n.d.). Many municipalities and corporations implement the use of PPPAs to reach and often exceed their renewable energy goals.

Figure 1: Diagram of a PPPA (Kent, n.d.)

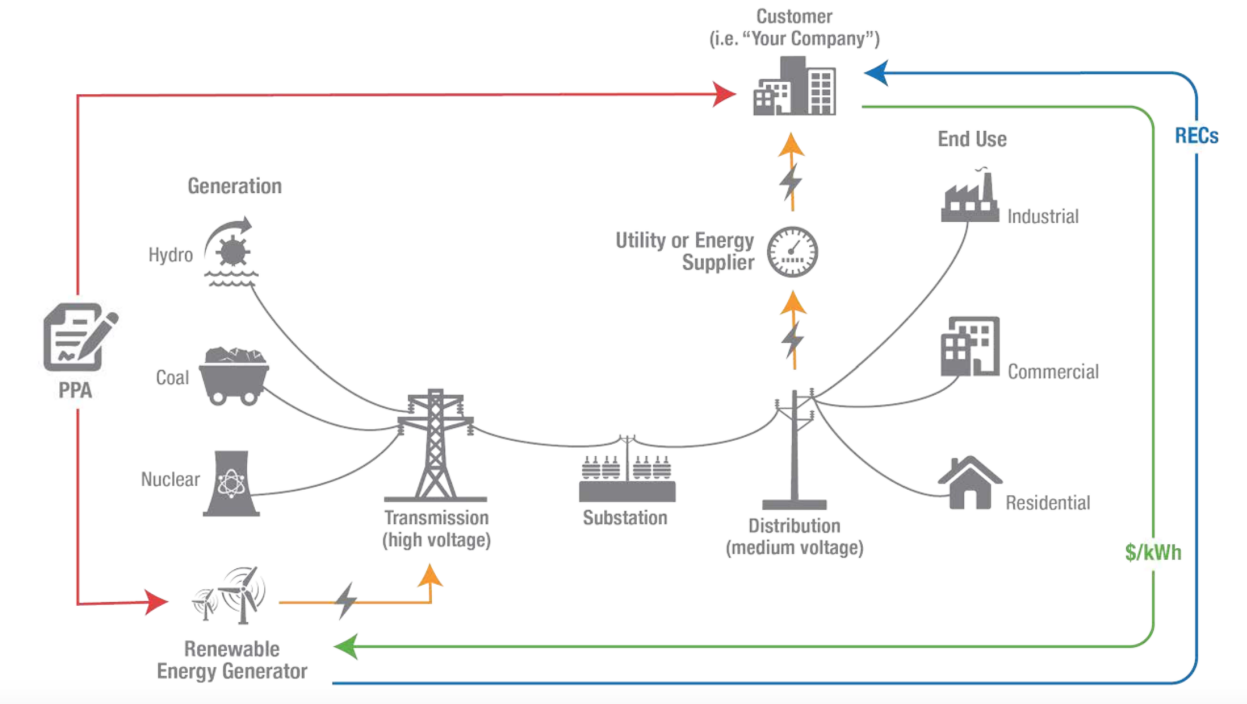

Figure 1 sourced from U.S. EPA (Kent,n.d.)

PPPA Characteristics (Kent, n.d.):

- The generator and the purchaser must be located on the same grid.
- A physical transfer of electrons occurs.
- The agreement is only permissible if the state in which the purchaser is located allows for direct retail access from the seller to the buyer (or via a third party).

The second type of PPA was the focus of our research. This type of agreement is commonly referred to as a virtual power purchase agreement or a VPPA. Similar to PPPAs, these agreements are rapidly growing in application around the world. The primary difference between a PPPA and a VPPA is that there is no physical transfer of electrons from the generator to the purchaser in a VPPA *(Kent, n.d.)*. VPPAs are growing in popularity in the corporate realm due to their flexibility and application toward company-wide renewable energy objectives across multiple regions. Municipalities, however, do not appear to be implementing these agreements as of yet. During our research, we found no confirmed examples of a municipality using a VPPA.

Figure 2: Diagram of a VPPA (Kent, n.d.)

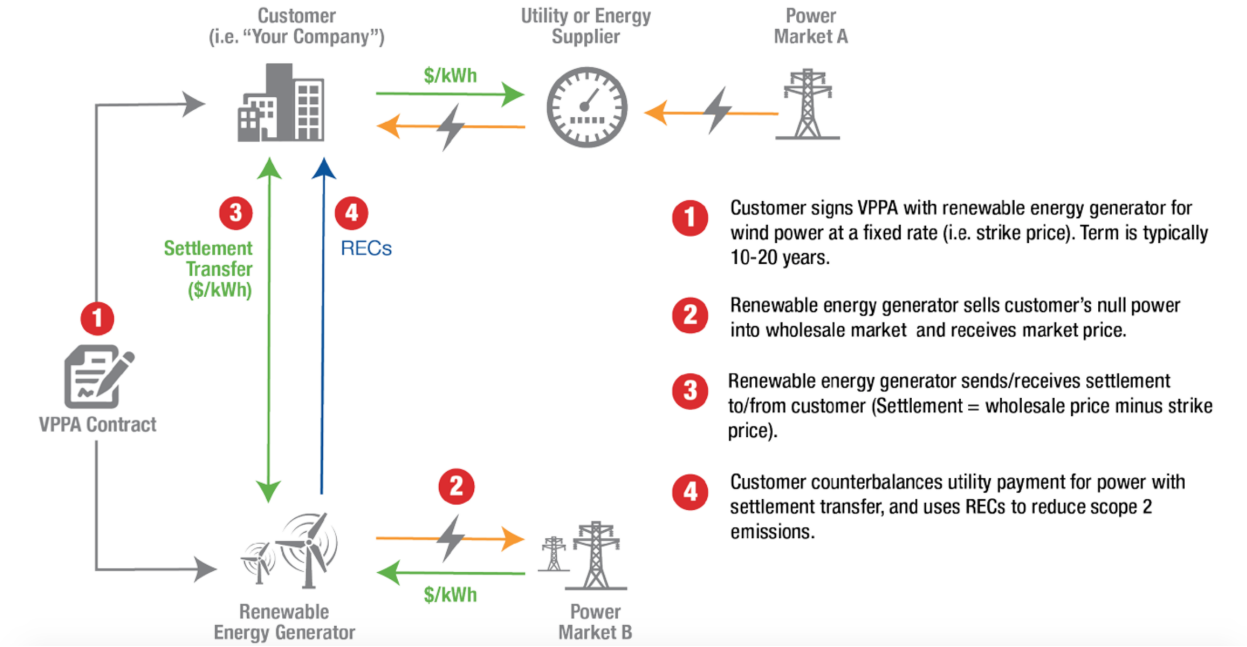

Figure 2 sourced from (Kent, n.d.)

VPPA Characteristics: (Kent, n.d.):

- The generator and the purchaser are not required to be connected to the same grid.
- There is no physical transfer of electrons.
- Direct retail access is not required.

Key Points:

- Both types of PPAs are a viable means for renewable energy procurement, however, some of the benefits of a VPPA are not necessarily applicable for municipal use. For a national company using energy in multiple states, a VPPA is a nice complement towards meeting overall renewable goals. However, due to the fact that municipalities do not need to meet renewable energy goals in multiple locations and may prefer to support more proximate renewable energy projects, this option may not be desirable.
- VPPAs do not require grid connectivity and do not involve a physical transfer of electricity. This allows for a wider selection of projects for the purchaser to choose from across a much broader geography. Further, it means that the buyer has access to lower cost renewable projects (e.g. wind plants in Texas or solar plants in Arizona).
- VPPAs are considerably more challenging to negotiate.
- Examples of municipal PPAs are common, but we found no confirmed example of a municipality implementing the use of a VPPA in our research.
- VPPAs require a monthly settlement be made between the buyer and seller.

Benefits

Purchase power agreements, both physical (PPA) and virtual (VPPA), are contracts that have the potential to provide the City of Columbus a reliable flow of renewable energy certificates (RECs). In comparison with purchasing RECs, both PPAs and VPPAs have the benefit of providing direct “additionality” for renewables (i.e. directly funding a new project). In either case, The City of Columbus would be directly investing in a specific new renewable energy generation facility, improving the energy sustainability of the city.

VPPAs are more of a financial contract (similar to an electricity futures swap agreement) rather than a physical electricity contract, as the buyer does not transmit and use the actual electricity being produced by the renewable energy generator *(Kent, n.d.)*. This is a benefit for VPPAs as The City of Columbus does not have to cover the logistics of transmitting and distributing the electricity, a potentially significant savings if the generator is located relatively far from Columbus. Both PPAs and VPPAs have fixed electricity prices, but only VPPAs have monthly settlements between the developer and the buyer *(Innovation in Power Purchase Agreement Structures, n.d.)*. Depending on whether the market price for electricity in the renewable project market is selling at greater or less than the contract electricity price, Columbus would either receive payments from or send payment to the generator. The settlements made with VPPAs could be financially beneficial, but could be risky depending on the structuring of the contact and the agreed contract price.

Case Analyses

Cummins Incorporated Case Study[2]

Cummins Incorporated manufactures and designs engines along with power generation systems. In this case study, Cummins describes how they met part of their sustainability goals of renewable energy through a VPPA from a wind farm. Cummins went about creating criteria to guide them in their decision making process related to their procurement of renewable energy. The options Cummins was considering were PPPAs, VPPAs, RECs and local utility contracts. Through the lens of the Corporate Renewable Energy Buyers' Principles, Cummins selected additionality and cost-effectiveness as two of their prioritized criteria. Additionally they deemed it necessary that the project have a tangible impact, and be transparent for stakeholders as secondary criteria. The Corporate Renewable Energy Buyers' Principles is an initiative led by World Resources Institute (WRI) and World Wildlife Fund (WWF) focused on promoting the growth and sustainable development of the renewable energy industry *(WRI, 2015)*. After in depth research analyses were conducted to determine which type of procurement method best suited Cummins, a VPPA was selected *(Zanchi & Kansal, 2018)*.

The cost-benefit analysis performed by Cummins was instrumental in receiving approval for the VPPA that they ultimately opted to utilize. In addition to the four criteria settled upon related to the Buyers Principles, Cummins deemed it necessary that their selection needed to mutually benefit the environment as well as the proximate community. The cost-benefit analysis was intended to ensure there was: acceptable

[2] See the link in the appendix for the full Cummins case study.

land, water, and wildlife impact, a positive local economic impact, consent from local community, and a like-minded project developer *(Danigelis, 2018)*. This rigorous framework is why Cummins was successful in developing a wind farm VPPA with limited, if any public backslash. We highly recommend the City of Columbus consider performing a similar analysis as renewable energy procurement decisions are made in the future.

Anheuser-Busch (with Enel Green Power) Case Study

With the help of Enel Green Power (EGP), Anheuser-Busch (AB) has declared that their beer production is now 100% powered by renewable energy (*Big Game, 2019)*. This is attributable to a VPPA established by the two companies in 2017 *(Anheuser-Busch and Enel Green Power, 2017)*. Enel Green Power's Thunder Ranch wind farm in Oklahoma is capable of producing enough electricity to allow Anheuser-Busch to purchase 600 GWh of renewable energy annually, covering half of AB's total electricity purchased each year. This agreement has been extremely effective and resulted in a large reduction of AB's CO2 emissions. Additionally, this VPPA has provided benefits for the local economy. Thunder Ranch provides the community with about $30 million in tax revenue, as well as $2.4 million paid to the individuals who own land with windmills on-site (*Big Game, 2019)*.

There are two lessons to be learned from this case study. First, VPPAs create powerful partnerships that promote the additionality of renewables. This is very apparent in that AB was able to directly influence EGP's ability to complete their Thunder Ranch wind farm project. The secured funding and guaranteed offload of

generated electricity made the project possible. Second, by purchasing renewable energy from a remote site, Columbus may be missing out on providing its own residents with economic benefits. The revenue generated by a local project would stimulate the local economy, however if the project Columbus is investing in is out of state, no gains are realized by its own residents.

Regulations & Barriers

There are several regulations and barriers that must be considered with any kind of PPA. While each of the two have some similarities in this area, there are important differences. The following section focuses on the similarities and differences relative to these barriers and regulations. Table 2 below provides a brief overview of some of the most important regulations and barriers we encountered during our research.

Table 2: Overview of Major Barriers and Regulations of PPPAs and VPPAs

Typical Barrier	PPA	VPPA
Require RTO or ISO		✓
Technical and vigorous contract	✓	✓
Must take or deliver energy	✓	
REC ownership unique to contract	✓	✓
Require market liquidity		✓
Require FERC Authorization	✓	
Dodd-Frank bound		✓

Table 2 highlights major barriers when navigating a typical PPA or VPPA.

Physical PPA Regulations and Barriers

An important factor to consider when determining if the implementation of a PPPA is viable is that the off-taker (purchaser) is required to obtain permission to participate in the energy market from the Federal Energy Regulatory Commission (FERC). FERC is the United States Federal Agency in charge of the regulation pertinent to the selling and transmission of all electricity and natural gas. Without FERC's permission, an off-taker is not able to engage with third-party entities authorized to purchase power at wholesale. While this option can be viable in some circumstances, it does carry risk in that contract agreement complexity is likely to arise given the nature and time of such long term agreements *(Penndorf, 2018)*.

Another barrier is that PPPA off-takers must have the ability to move the energy once they have earned the title to obtaining such energy. The off-taker must be able to move or find a third party to move the purchased energy to its end location. Effectively, this means ensuring the transmission, distribution, and final delivery of the energy purchased. While this can be done with a third-party as mentioned above, third-party agreements can still be difficult to negotiate given the complexity of the contracts and long-term agreements *(Penndorf, 2018)*.

Virtual PPA Regulations and Barriers

While VPPAs are a relatively new and less-regulated agreement compared to PPPAs, some regulations have been put into place. One of these is that VPPAs are bound to the Dodd-Frank Wall Street Reform and Protection Act or "Dodd-Frank". Dodd-Frank is federal law that regulates the financial sector *(What is Dodd-Frank Act?, n.d.)*.

One set of agreements covered under Dodd Frank include swap agreements. VPPAs are a form of financial futures swaps since the buyer receives RECs and net revenues from the settlement price in the power markets in exchange for (or “swapped” for) a fixed contract price for the VPPA . PPPAs rarely involve swaps but rather represent the physical purchase of power. *(Penndorf, 2018)*.

Another potential barrier for VPPAs, is they require liquidity in the market. This means that an independent power producer (IPP) or the project developer of the renewable project must be able to sell power to the grid directly. This requires that VPPAs are located in a market managed by a regional transmission organization (RTO) or independent system operator (ISO). Most regional power markets are organized around an RTO or ISO. Such markets include but are not limited to Pennsylvania New Jersey Maryland Interconnection (PJM), New York ISO (NYISO), Southwest Power Pool (SPP), etc *(Industries - RTO/ISO)*. Given that IPPs are allowed to sell directly to the grid in RTOs and ISOs, these regional markets allow for a smooth functioning VPPA. Without such market liquidity, VPPAs are not easily implemented. This is the case in areas where energy markets are vertically integrated, meaning one entity is in charge of transmission, generation, and distribution of energy, one primary example is the SERC region which is dominated by Southern Company.

Negotiating an Economically Efficient VPPA

One of the most important factors of negotiating an effective PPA is establishing a price that ensures the agreement does not increase the cost of energy for the purchaser. This is impacted directly by the degree to which the purchaser’s electricity

market is correlated with the generator's electricity market. Successful agreements benefit both parties in that the the purchaser cheaply obtains RECs for their contribution to the generator's project, and the generator secures funding and a guaranteed offload of electricity created by their project. In a PPPA, the established price is referred to as the contract price. In a VPPA, the negotiated price is commonly referred to as a strike price *(Markets and VPPA's, n.d.)*.

Many power purchasers refer to the ability of PPAs to "hedge" electricity prices. This essentially refers to whether or not the deal secures the RECs for the purchaser at or below their own regional market price. If the contract or strike price is lower than market price, the PPA ultimately saves the purchaser money. However, this is not all that simple to implement.

In a PPPA, the purchaser only needs to worry about their own market, making savings as a result of a fixed contract price easier to achieve. In a VPPA the issue becomes considerably more complicated. Due to the difference in price of electricity in the purchaser's market compared to the price of electricity in the generators' market, a monthly settlement must be made to compensate for the different rates received for the electricity. For this reason, the agreement is only effective if the two markets are correlated since the purchaser must be able to pay the for the procured renewable energy using the higher rate received in their own market. An example of an inefficient agreement is depicted by Figure 3 on the next page.

This aspect of VPPAs must be extensively researched prior to entering an agreement. Our team conducted an analysis using data retrieved from the U.S. EIA to estimate correlation between the regional transmission organizations (RTOs) in order to

determine which market would be the least risky for Columbus to enter a VPPA in. Based on our results depicted in Table 1 in the methods section, we concluded the New England Massachusetts Hub (Nepool MH) and the Indiana Hub have been the most closely correlated with the PJM West market. This means projects in these markets are the most likely to produce economically efficient outcomes.

Figure 3: Example of an Inefficient VPPA (Markets and VPPA's, n.d.)

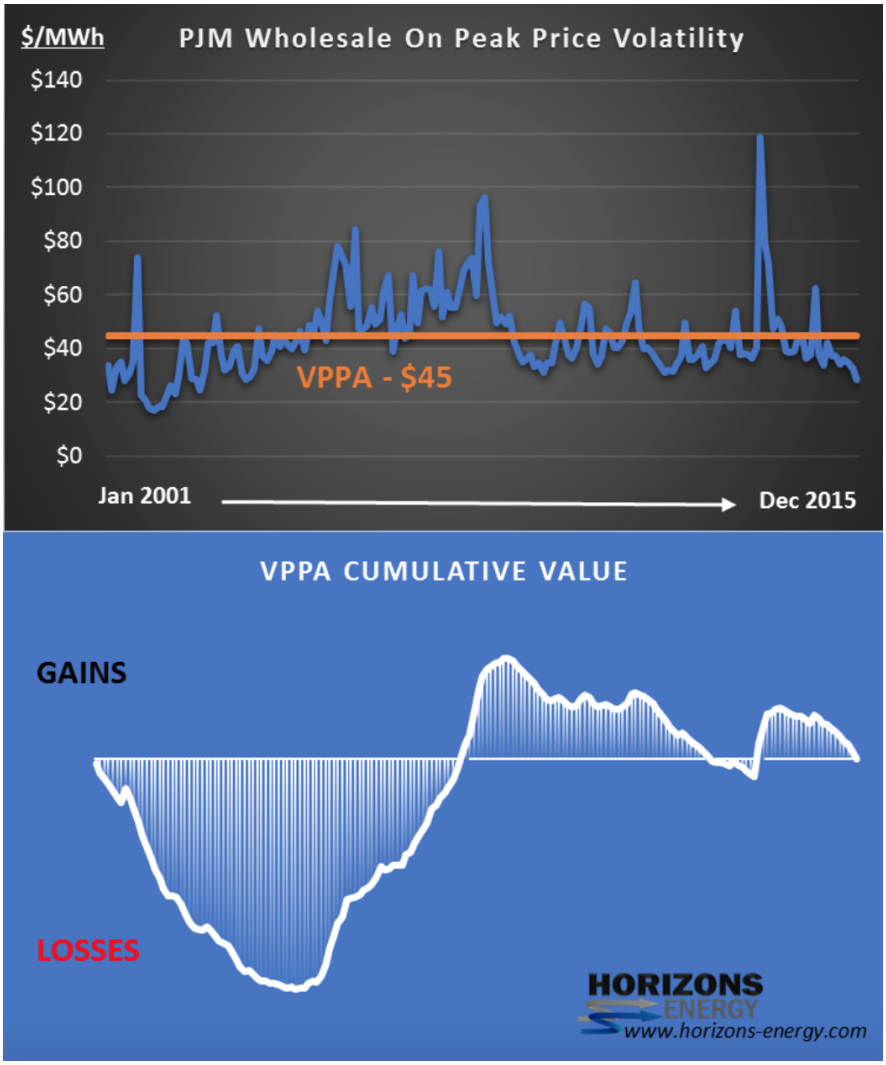

Figure 3 (sourced from Horizons Energy) depicts a VPPA which did not effectively "hedge" the price of electricity during its 15 year contract duration. In essence, this contract was not economically efficient.

Future Outlook

Power purchase agreement prices vary by energy source, production region, electrical grid, and contract year. As previously mentioned, it is important to consider the correlation of the buyer's and generator's market while determining a suitable market from which to purchase. For the purpose of differentiating agreements based on production source, solar or wind, historical and future pricing data will help the City of Columbus narrow down which types of PPAs to pursue. While many individual PPA contract prices are confidential, Berkeley Lab's Electricity Markets and Policy Group has compiled public data on national average levelized PPA prices, for both solar and wind, which can be viewed in the table below.

Table 3: Solar and Wind PPA Prices by Contract Year (Power Purchase Agreement, n.d.), (Wind Power Purchase Agreement, n.d.)

Contract Vintage	National Average Levelized PV (Solar) PPA Price (Real 2017 $/MWh)	National Average Levelized Wind PPA Price (Real 2017 $/MWh)
2006	230.6	-
2007	210.0	-
2008	186.7	66.9
2009	158.4	70.9
2010	134.0	61.6
2011	107.4	44.3
2012	79.6	39.0
2013	65.9	27.8
2014	53.8	24.7
2015	46.2	28.4
2016	38.1	26.7
2017	41.4	18.91
2018 Predicted	22.3	-

Table 3 lists average levelized PPA prices for both solar and wind by date of contract. All prices are in real 2017 dollars. No prediction for wind PPA prices was present by Berkeley Lab's Electricity Markets and Policy Group.

While both solar and wind prices have decreased over the past decade, wind PPA prices have been significantly lower. As solar technology continues to advance and become cost effective, PPA prices can be expected to continually decline and level off. The following graph is a snapshot of the above data compared to national wholesale electricity prices from the U.S. Energy Information Administration (EIA).

Figure 4: PPA Prices in Relation to National Wholesale Electricity Prices (U.S Energy Information Administration, n.d.)

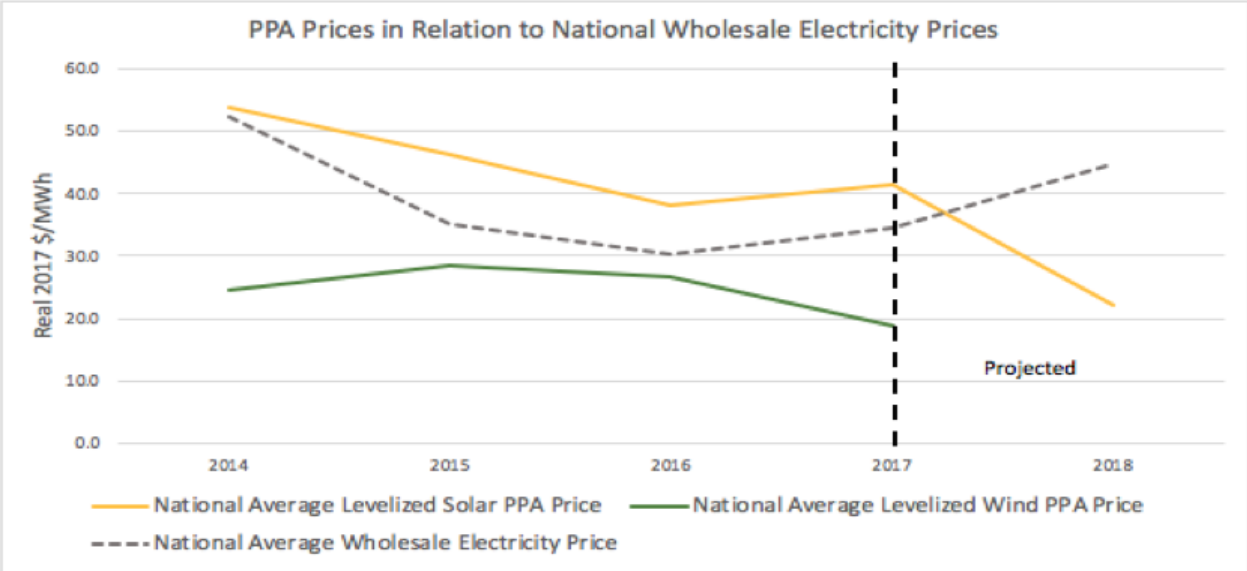

Figure 4 compares the price data from Table 3 above with the national average wholesale electricity price from the Energy Information Administration. No 2018 data or projection was available for wind PPA prices.

From the data above, our recommendation to the City of Columbus is to first look in to purchase agreements for wind energy projects, due to their historically lower contract prices. Solar PPAs have only recently been priced lower than the average national wholesale electricity price.

Another important factor influencing PPA pricing is the Federal Renewable Energy Production Tax Credit (PTC). This program provides a tax credit amount between $0.01- $0.023 per kilowatt hour for the first ten years of operation for select renewable energy production facilities *(Renewable Energy Production Tax Credit, n.d.)*. This tax credit has impacted the PPA and other renewable markets by artificially lowering prices. The phasing out of this program in the next five years will surely affect PPA prices in the future. This is one main reason we suggest entering into an agreement in the next few years if the city chooses to do so.

Recommendations

1.) Conduct an analysis similar to the one conducted by Cummins.

2.) Determine the desired outcomes of the procurement method.

- Before choosing the specific project and procurement type (VPPA, PPA or RECs), it is important to determine the amount of energy that is to be procured from the investment.
- Is “additionality” of new specific projects a priority? If so, specific project VPPAs or PPAs are the best route rather than RECs.
- Does Columbus wish to support only local/regional projects or are lower cost projects outside of Ohio more desirable? This affects whether a VPPA or PPA is applicable.
- Work with the community to determine how involved they would like to be in the project, and if they would be willing to incur a slightly higher rate if necessary to fund different types of projects.

3.) If a VPPA is to be pursued, be sure to consult an expert.

- Due to their complicated and dynamic structure, VPPAs are difficult to both understand and negotiate. Additionally, there may be regulations that must be complied with. Columbus should most definitely consider consulting someone with experience negotiating market-based renewable energy deals, preferably someone who has experience negotiating VPPAs specifically.
- The relationship between Columbus' electricity market and the electricity market of the selected project should be extensively understood. Future projections of electricity prices should also be made as well.
- Determining optimal project locations will require in depth understanding of national electricity markets and renewable energy production per region. There can be a very significant difference in the project costs of wind and solar in different states and regions due to locational difference in wind and solar resources as well as regional production and grid hook-up costs.

Conclusion

It is clear that the use of virtual power purchase agreements is an efficient and flexible method of procuring renewable energy. What is not as evident, is how well suited these agreements are for municipal use. Some of the advantages VPPAs provide over PPPAs are not as useful for municipalities, such as the fact that VPPAs allow for the purchaser to achieve renewable energy goals for facilities in multiple grids. This is not to say that VPPAs are not viable for municipal implementation. There is certainly potential for a VPPA application in municipalities depending on the intended outcomes

and willingness of the municipality to negotiate and understand the agreement as well as whether a municipality wants to buy into projects outside its region.

For Columbus to pursue a VPPA, far more research and a much more extensive evaluation than we have provided should be conducted. Following a procedure similar to the one Cummins used to decide which method of renewable energy procurement is must suitable would likely benefit Columbus greatly. Part of this process should also include consultation of an individual or firm that has experience working with VPPAs.

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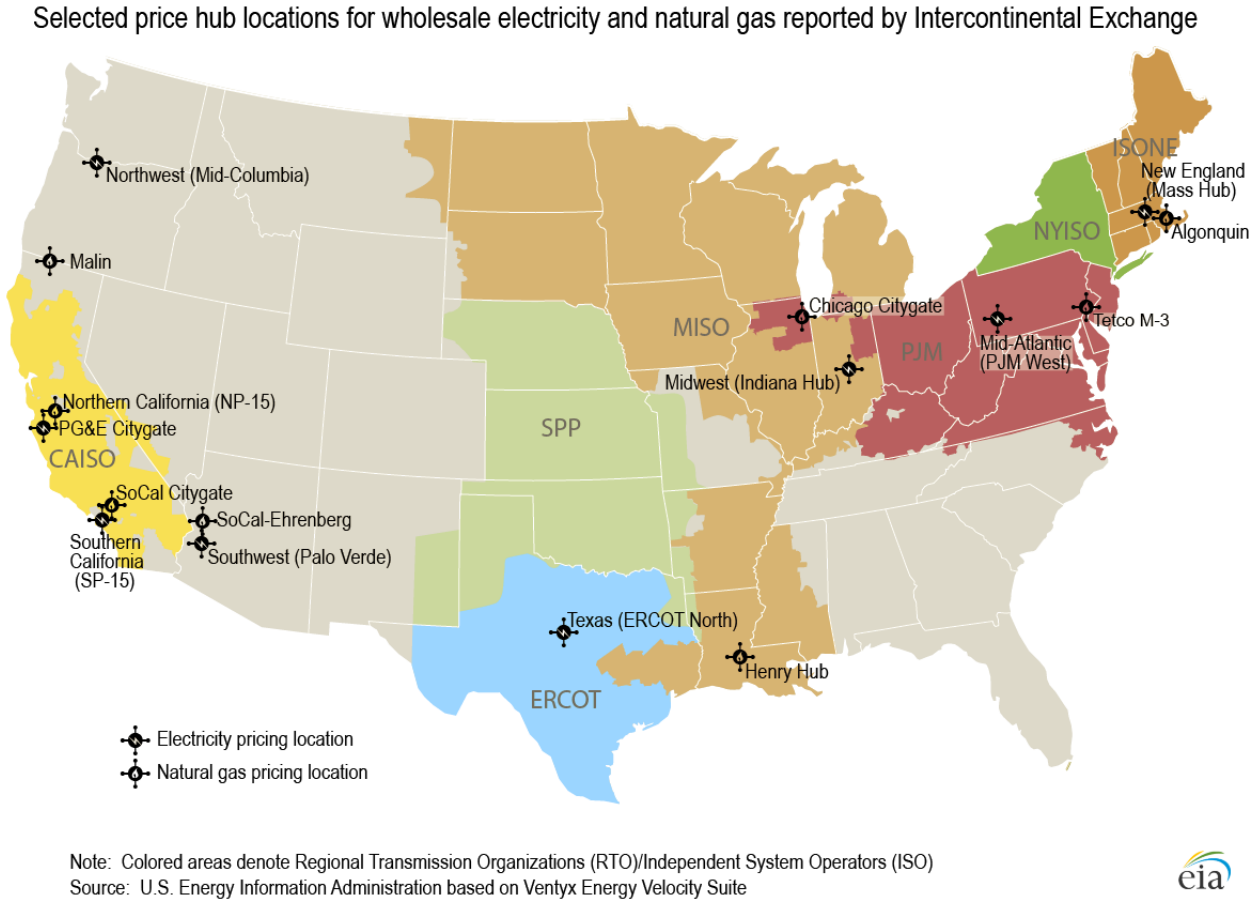
Appendix

Figure 5: U.S RTO/ISO Map (Source: U.S. Energy Information Authority)



Given the nature of this report, nearly all information came from websites, articles, and case studies found online. Data was obtained via the Intercontinental Exchange (ICE) and the U.S. Energy Information Administration (U.S. EIA). The following are key datasets and resources used in this report. These could be of use in further research endeavors.

Datasets

Table 1
Source: U.S. EIA with permission from the International Exchange
Link: https://www.eia.gov/electricity/wholesale/
File Name: Wholesale_Electricity.xlsx
Description: This data was retrieved from the U.S. EIA website and was used to derrive average on-peak wholesale electricity data used in our analysis of market correlation.

Table 3 & Figure 4
Source: International Exchange
Links: https://emp.lbl.gov/wind-power-purchase-agreement-ppa-prices & https://emp.lbl.gov/pv-ppa-prices
File Names: PV_PPA_Prices_Data.xlsx & Wind_PPA_Prices_Data.xlsx
Description: This data was retrieved from the Intercontinental Exchange in order to provide insight related to the current and potential future cost of PPAs. It was unclear whether this data was pertinent to all types of PPAs or a specific type.

Helpful Literature

Title: Financial Power Purchase Agreements
Source: U.S EPA
Description: This source provides a concise description of what a financial (virtual) power purchase agreement is and why organizations use them. Several other useful links are present on this page.

Title: Introduction to Virtual Power Purchase Agreements
Source: Christopher Kent, Published by the U.S. EPA
Description: This source is a comprehensive introduction to virtual power purchase agreements. A large portion of our research was based off of information from this source.
Link:https://www.epa.gov/sites/production/files/201609/documents/webinar_kent_20160928.pdf

Title: Innovation in Power Purchase Agreement Structures
Source: World Business Council for Sustainable Development (WBCSD)
Link: https://cebds.org/wp-content/uploads/2018/03/WBCSD_Innovation_PPA.pdf
Description: This source describes how PPAs have evolved and been incorporated by corporations. It highlights some of the innovations that have made these agreements so successful at expanding the renewable energy generation sector.

Title: Multi City Renewable Energy Request for Information
Source: The City of Boston
Link: https://www.boston.gov/sites/default/files/document-file-07-2018/multi_city_renewable_energy_rfi.pdf
Description: This source details an RFP from the City of Boston requesting information on large-scale renewable energy purchase agreements. It does not specifically request a VPPA, however, if contacted, they or another city that is part of The Consortium might have useful information.

Title: Choosing Off-site Renewable PPAs for Environmental and Social Impact: A Case Study on Cummins' Virtual Power Purchase Agreement in Indiana
Source: Roberto Zanchi and Rachit Kansal, Published by Rocky Mountain Institute
Link: www.rmi.org/insight/choosing-offsite-renewable-ppas/
Description: This source provides an extremely in depth case example of how Cummins Inc. determined how they would source renewable energy. The framework of their decision making process could be exceptionally valuable for any entity looking into sustainably sourcing renewable energy.