Opportunity Between the Turbines: A Willingness-to-Pay Experiment Regarding Co-Location Activities with the Coastal Virginia Offshore Wind Farm

Shannon Fluharty

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Jonathan van Senten
Darrell Bosch
Klaus Moeltner

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ABSTRACT

With shipping routes, fisheries, conservation areas, recreation, and other maritime industries competing for space off Virginia's coastline, integrated solutions for marine areas may offer a way to limit conflict and maximize productivity. Countries across the world are researching the different ways in which the space between turbines can be utilized to provide economic and environmental benefits. The act of coupling other maritime activities with offshore wind farms is often referred to as co-location. As Virginia constructs the first offshore wind farm in United States Federal waters, there are new opportunities for co-location that could benefit the Virginia economy. Using data from a choice experiment and random utility modeling, this research quantifies Virginia public preferences for various co-location options within the lease area of the Coastal Virginia Offshore Wind (CVOW) farm. Our estimated WTP values show Virginia's public preference for the addition of co-location to the CVOW lease area to be upwards of $20 per 1,000 acres of activity. Our estimates can be compared to implementation and management costs of each activity to determine potential for incorporation of certain co-location techniques. The experimental design of this study can be applied to other offshore wind installments around the world.

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GENERAL AUDIENCE ABSTRACT

With shipping routes, fisheries, conservation areas, recreation, and other maritime industries competing for space off Virginia's coastline, integrated solutions for marine areas may offer a way to limit conflict and maximize productivity. Countries across the world are researching the different ways in which the space between turbines can be utilized to provide economic and environmental benefits. The act of coupling other maritime activities with offshore wind farms is often referred to as co-location. As Virginia constructs the first offshore wind farm in United States federal waters, there are new opportunities for co-location that could benefit the Virginia economy. Using a Stated Preference Choice Experiment and economic valuation methods, this research quantifies Virginia's public preferences for various co-location options within the lease area of the Coastal Virginia Offshore Wind (CVOW) farm, such as: a seaweed aquaculture farm, a seaweed forest, and a research area. Our estimated WTP values show Virginia's public preference for the addition of co-location to the CVOW lease area to be upwards of $20 per 1,000 acres of activity. Our estimates can be compared to implementation and management costs of each activity to determine potential for incorporation of certain co-location techniques. The experimental design of this study can be applied to other offshore wind installments around the world.

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1. Introduction

An increase in global development has led more of the planet's population to call coastal communities home (Buck and Langan 2017). Seaside ports support prospects for tourism, trade, and jobs, which, in turn, entices coastal development (Buck and Langan 2017; Census Bureau 2020). According to the United States (U.S.) Census Bureau, between 1960 and 2008 there was an 84.3% increase in population for coastal areas and 64.3% increase for non-coastal areas (Census Bureau 2020). A challenge that accompanies growth along the shorelines of the United States is the finite amount of space in those regions. With fewer coastal options to support a growing population; regulators, developers, and researchers are looking for ways to utilize offshore environments for sustainable expansion of large-scale energy and food production (Campbell et al. 2019; United States and Executive Office of the President 2020; Commonwealth of Virginia and Executive Office of the Governor [Ralph Northam] 2019; Holm, Buck, and Langan 2017).

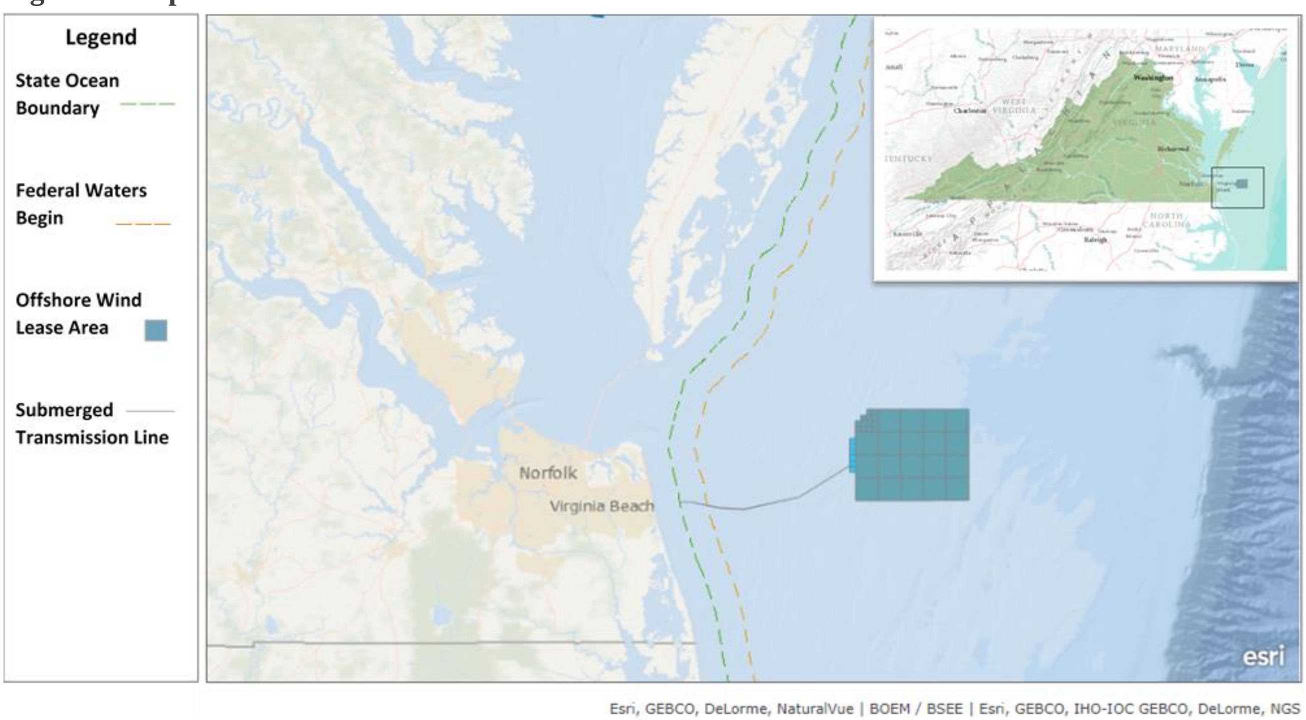
As population rises, so does the demand for protein sources. The U.S. is rising to meet this demand, with new backing for the United States seafood industry stemming from the Executive Order on Promoting American Seafood Competitiveness and Economic Growth (United States and Executive Office of the President 2020). This Executive Order specifically promotes the offshore expansion of the aquaculture industry, due to limited coastal and riparian real estate. Separately, to meet the global need for cleaner energy sources, the energy sector is also pioneering avenues for this offshore expansion which can pave the way for other industries to follow suit. This innovation comes in the form of offshore wind energy. With construction of an offshore wind farm 27 miles off the Virginia Coast, come opportunities for co-location (coupling multiple activities within a single area of ocean space) to allow multiple marine industries to simultaneously co-exist. Fortunately, co-location or multi-use is a suitable solution to some of the spatial limitations of our developing world (Holm, Buck, and Langan 2017). This paper will estimate the willingness-to-pay of the Virginia (VA) public to combine various marine activities with the VA offshore wind farm that is currently under construction.

1.1 Background

In the wake of the United States' expansion of the offshore wind (OSW) industry are opportunities for marine businesses to improve and innovate. The surge of the United States OSW industry has undoubtedly elicited mixed feelings among stakeholders about the modes by which to execute these opportunities for innovation (Buck and Langan 2017). Some of the mixed feelings that stakeholders have reside in the unknown effects of OSW on the surrounding marine environment, ability to maintain commercial fishing activities, and ocean access rights (Buck and Langan 2017; Krause and Mikkelsen 2017). The national transition to renewable energy has led Governor Ralph Northam, of Virginia to sign an executive order committing the Commonwealth to a goal of 100% reliance on renewable energy by the year 2050 (Commonwealth of Virginia and Executive Office of the Governor [Ralph Northam] 2019).

In efforts to incorporate more renewable energy into VA's market, Dominion Energy® is building the Coastal Virginia Offshore Wind (CVOW) project ("Coastal Virginia Offshore Wind" 2020). Dominion Energy® is the electricity utility that provides a majority of Virginia's power. The CVOW project is located within a 2,135-acre site regulated by the Bureau of Ocean Energy Management (BOEM), which lies 27 miles off the coast of Virginia Beach, VA (Figure 1) ("Coastal Virginia Offshore Wind" 2020). This commercial wind deployment is intended to connect to electrical grids within 13 eastern states and Washington, D.C., to deliver up to 8.8 million megawatts (MW) of offshore wind energy to consumers annually ("Coastal Virginia Offshore Wind" 2020). The CVOW project is expected to include between 180-195, 12-MW turbines which "combined will provide enough energy to serve more than 650,000 customers" ("Coastal Virginia Offshore Wind" 2020). To transmit the generated energy, a submerged power cable connecting the turbines will be buried under the seabed and will ultimately come ashore through a 1,000-meter conduit installed under the beach ("Coastal Virginia Offshore Wind" 2020). As of summer 2020, the CVOW two-turbine pilot study consisting of two 12-MW turbines within the lease area was activated. The purpose of the pilot study is to test the turbines prior to construction of the commercial wind farm ("Coastal Virginia Offshore Wind" 2020).

Figure 1: Map of the CVOW lease area.



The U.S. expansion of the OSW industry was preceded by Denmark, which as a country, has been generating electricity from OSW for the past 30 years (Sawyer 2010). Countries across the world are recognizing the importance of marine coexistence and are researching ways in which unused space between OSW turbines can be employed to provide economic and environmental benefits and increase the scale of ocean food production (Buck and Langan 2017; Craig 2018; Rockmann, Lagerveld, and Stavenuiter

2017). Examples of this effort include the coupling of a variety of fisheries, marine protected areas, and several forms of aquaculture within the vacant space of offshore wind farms (Buck and Langan 2017). The act of coupling other maritime businesses and activities with OSW is often referred to as co-location. As existing human uses such as shipping routes, fisheries, conservation areas, recreation, and other maritime businesses compete for space off U.S. coastlines, growth of the OSW industry introduces prospects for exploration into which co-location techniques can contribute as solutions to ocean use-conflicts (Holm, Buck, and Langan 2017).

The ocean is a vital resource to a broad range of stakeholders (Buck and Langan 2017). Introducing a new industry into the waters off Virginia's coast requires additional developments within the science-policy nexus to foster the co-existence of marine activities (Krause 2015; Buck and Langan 2017). The science-policy nexus includes permitting, regulatory, and marine conservation measures that accompany human uses for the ocean (Buck and Langan 2017). While permitting multiple activities within a single lease area can be challenging, advancements within science policy could contribute to a reduction in the footprint associated with human development (Krause and Mikkelsen 2017; Buck and Langan 2017). The rapid changes within VA's energy industry make it crucial for utility companies to understand the preferences and values of the public before the implementation of new techniques and management strategies, because the power of the public, in terms of opposition and support, should not be underestimated (Haggett 2011; Krause and Mikkelsen 2017).

With a combination of innovation and refined policy, VA could economically benefit from co-locating offshore wind farms with various maritime businesses to maximize ocean space already intended for human development, while simultaneously engaging in marine conservation efforts (Haines et al. 2018; United States and Executive Office of the President 2020). Utilizing stated preference choice experiment (CE) techniques and willingness-to-pay (WTP) valuation, this study seeks to provide an opportunity for the VA public to share their preferences for certain co-location activities associated with the CVOW project and estimate Virginia public WTP for the integration of co-location activities within the lease area of the CVOW project. It is hypothesized that the VA public would be willing to pay a positive annual amount (in the form of increased taxes) to incorporate a combination of marine activities, at certain levels within the unused ocean space of the CVOW farm.

1.2 Co-location Activities

"Activities planned in the offshore realm require strong policy backing with effective governance arrangements and clear multi-use management goals" (Krause and Mikkelsen 2017). While there are various forms of co-location activities that are compatible with offshore wind farms, deciding which co-location techniques to incorporate within a wind farm lease area is dependent upon location, size, distance from shore, local and federal regulations, available technology, and wind farm layout, to list a few (Buck and Langan 2017). The potential success of co-locating a certain activity with an OSW farm will vary based on the qualities and characteristics of each OSW installment. Additionally, each multi-use technique is accompanied by its own set of policy challenges. With awareness of the obstacles that accompany permitting multi-use techniques, discussing the implementation and management of co-location activities is not within the scope of this research.

One form of co-location that is already present within the open ocean space of the CVOW lease area is public access. Historically and currently, the CVOW lease area hosts regular activity from recreational and commercial fishing, boating, and charter operations. With the intent to minimize the impact of the OSW farm on current offshore pursuits, it is unlikely Dominion Energy® or BOEM will restrict public access within the CVOW lease area (Webster and Porter 2020). Allowing the public to access the open ocean between the turbines for recreation and commercial fishing is therefore considered the status quo (SQ) operations throughout this experiment.

Communities within the U.S. have experienced economic success with allowing public access within the space between turbines of OSW farms (Carr-Harris and Lang 2019; Kularathna et al. 2019). That economic success comes in the form of recreational benefits to anglers, encouraged purchasing of boating and fishing permits and licenses, and additional opportunities for tourism (Kularathna et al. 2019; Carr-Harris and Lang 2019). Increased tourism opportunities include attracting visitors to the nearby coastal community to view the turbines. According to Carr-Harris and Lang (2019), the installation of the Block Island Wind Farm in Rhode Island, U.S. waters has been linked to increased rental rates in the surrounding coastal community with tourists interested in visiting the Block Island Wind Farm.

Offshore structures are also known to attract marine species which create reefs attached to the monopoles of the turbines (Langhamer 2012). In a survey conducted by Smith et al. (2018), anglers reported that the Block Island Wind Farm has improved fishing areas in terms of increased species abundance (Prevost 2019; Smith et al. 2018). An additional study which interviewed stakeholders about their preferences for co-location of activities with a new offshore wind installment in Southern Japan found that stakeholders anticipated positive species ‘spillover’ from the artificial reef effect from the aggregation of fish around OSW turbines and stakeholders preferred to have fishing access to the region (Kularathna et al. 2019).

Based on the specific characteristics and available technologies associated with the CVOW project, this study focuses on three additional co-location activities as viable options to couple with the CVOW farm. The three types of co-location (or attributes) displayed in the CE were combined at varying levels to compose co-location profiles (discussed in detail later). The three types of co-location techniques are as follows: (1) a seaweed aquaculture farm, (2) a non-harvested seaweed forest, and (3) a designated research area. During the survey, respondents are provided with the option to willingly accept an annual tax for the implementation of various combinations of co-location techniques based on the economic and environmental implications associated with each activity, discussed in the following section, or stick with the SQ of “unlimited public access” to otherwise featureless between-turbine space. Justification and literature reviews for each co-location activity included in this research are incorporated in the subsequent 'Literature Review' section of this paper.

2. Literature Review

This literature review consists of peer-reviewed research, books, and articles discussing various co-location strategies and offshore wind related marine research. In addition to the scientific justification behind each co-location activity chosen for this research, a further literature review was included to validate and provide background information on why co-location is an economically and environmentally viable technique that should be considered for the CVOW project.

2.1 Existing Public Willingness-to-Pay for Co-Location Literature

Current literature regarding co-location techniques focuses on the economic and technological feasibility of certain types of co-location. While many papers research the perception of offshore wind as an energy source (Bates 2016; Knapp and Ladenburg 2015) and discuss the economic feasibility of certain co-location activities with offshore wind around the world (van den Burg et al. 2016; Rockmann, Lagerveld, and Stavenuiter 2017; Kite-Powell 2017; Buck and Langan 2017), academic literature is specifically deficient in addressing the public WTP for certain co-location activities.[1]

Results from the database search did include two studies that are moderately related to the research in this paper. The first study by Dalton et al. (2020) evaluated the WTP of boaters to participate in fishing trips within proximity of OSW turbines. The authors used a stated choice survey to assess the potential impacts of offshore wind farms on the welfare of recreational boaters in Rhode Island (US) waters (Dalton et al. 2020). The researchers asked recreational boaters to choose which attributes they would prefer in a boating trip. Attributes included location, proximity to a wind farm, amount of nearby boating activity, main activity during a trip, and trip costs (Dalton et al. 2020). Overall, this study found that in Rhode Island, the value of a recreational boating trip within proximity to OSW farms was substantially reduced (Dalton et al. 2020). The limitation of this study is that it only considers the preferences of recreational boaters for fishing trips within proximity to wind farms. The study merely presents one co-location option to a very specific group of individuals. Additionally, public access is assumed as the status quo for the CVOW project, so within the CVOW lease area boaters will have to adapt to the new turbines regardless of preference.

A separate study executed in Japan systematically evaluated potential co-existence options that can be viable in two of Japan's Marine Renewable Energy project areas (Kularathna et al. 2019). Data collection involved a broader level of key stakeholders in interviews and questionnaires. This experiment identified five main co-existence opportunities to present to key stakeholders. The five main options included: "sharing in-situ, real-time oceanographic information; using Marine Resource Energy structures as

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[1]A search within Google Scholar and Virginia Tech's database of Libraries Worldwide, using the terms 'public' and 'offshore wind' and 'willingness to pay' and 'co-location' revealed no studies directly related to the research conducted in this paper.

artificial reefs and support structures for commercial fishing; co-location with other industries such as leisure and tourism, aquaculture, etc.; sharing generated electricity for local users at a subsidized rate; and use of local resources to construct and operate the power plant, creating business involvement opportunities" (Kularathna et al. 2019). Kularathana et al. (2019) collected data on the stakeholder preferences for each activity but did not calculate their WTP for each co-existence option. The results of this study varied by key stakeholder groups based on the perceived impacts on their daily lives, which is consistent with choice logic (Kularathna et al. 2019). They found that residents who have less interaction with the ocean preferred the stakeholder engagement aspect, intending to create local benefits for marine industries; fishers generally preferred the option of sharing oceanographic information[2]; and the general public and project developers preferred the option of using local resources to construct and operate the power plant, creating business involvement opportunities (Kularathna et al. 2019). While this study did incorporate stakeholder preferences for various co-existence activities, it did not quantify the WTP, in dollars, for each activity.

Ultimately, there is an absence of academic research quantifying the public WTP for the incorporation of co-location activities with OSW farms. Specifically, this type of analysis is non-existent concerning the CVOW farm. Quantifying public preferences for co-location in terms of the U.S. dollar can help inform policy and private sector decisions about the management of the CVOW farm. Furthermore, providing the public with the option to voice their preferences can result in a higher rate of consensus. Research supports that when the public is asked to share their preferences related to conservation and environmental matters, they are more likely to accept the final management decision even if it was not their desired outcome (Young et al. 2016). The ensuing sections of this literature review will summarize the current literature regarding the three chosen co-location activities and other positive externalities that can arise due to co-location.

2.2 Justification of Co-Location Activities

The three co-location activities chosen for this research were dependent on presently available knowledge and compatible technology within the offshore aquaculture, recreation, and fishing industries. Literature reviews on various potential co-location techniques were conducted and compared with the known characteristics of the CVOW project to further determine which co-location activities would be included in this study. The CVOW project's considerable distance from shore (approximately 27 miles) presents limitations and challenges regarding presently compatible co-location techniques.

2.2.1 Seaweed Aquaculture

Based on the distance from the shore of the CVOW project and available offshore mariculture technology, one form of co-location that has the potential to be economically successful and environmentally compatible with the CVOW farm is macroalgae or seaweed aquaculture. Seaweed has several uses in multiple markets and is becoming a more popular alternative to land-grown products in various food and feed markets (van den Burg et al. 2016). According to the World Bank, seaweed can also be harvested and

[2]Data collected for regulatory purposes.

integrated into the biofuel industry (World Bank Group 2016). Industries and researchers are discovering additional creative uses for seaweed that can expand the seaweed market globally. Emerging technologies have had success transforming seaweed into decomposable ‘plastics’, utilizing components of seaweed for the nutraceutical industry, and developing edible packaging material (Siah, Aminah, and Ishak 2015).

Additionally, seaweed aquaculture is considered a zero-input crop, which means it does not require feed, freshwater, land, or fertilizer for growth; which is why it is often considered the most sustainable type of farming (Gertz 2017). Additionally, investigators have discovered that as an alternative feed for livestock, the U.S. production of seaweed can reduce soy imports, and combat deforestation that occurs in soy-producing countries (Wassef et al., 2005).

Common methods for seaweed farming involve anchored rope systems in which ropes are tethered to buoys and anchored in some fashion to remain in place (Figure 2) (Forster et al. 2008). It is not in the interest of this research to argue which method of farming macroalgae is best, however, the anchored rope system is chosen as the aquaculture method for this study based on the simplicity of the technique and known success as an offshore aquaculture method used in the Atlantic Ocean (Gertz 2017).

In addition to the diverse markets macroalgae can be sold, macroalgae also provide important environmental benefits during growth, such as sequestration of carbon dioxide and nitrogen, stimulation of healthy habitats for marine species, and storm surge protection (Buck and Langan 2017). Seaweed also acts against climate change and ocean acidification because it can reduce ocean eutrophication as nutrients are taken up during growth and are transformed by the harvesting process (He et al. 2008). According to the World Bank, one acre of seaweed can absorb about 8.27 tons of carbon dioxide (CO_2) and 161.87 pounds of nitrogen (N) annually (World Bank Group 2016). Naturally, when seaweed is harvested after an average of 20-40 days of growth, the absorption of CO_2 and N is interrupted, and the seaweed does not have the chance to provide the same habitat benefits typically provided by wild seaweed forests.

Offshore aquaculture offers marine spatial planning solutions as well. As the United States’ coastal communities become more crowded with riparian and coastal aquaculture farms, offering aquaculturists the opportunity to expand their operations offshore can reduce nearshore conflict (Krause and Mikkelsen 2017; Finley 2017). By providing aquaculturists with additional areas to cultivate food, there are added opportunities to meet the growing demand for food nationally (Michler-Cieluch and Kodeih 2008). Not only does offshore aquaculture reduce nearshore disputes over water usage, but it can benefit the aquaculturists financially. Studies show that if located offshore, aquaculture operations can be larger resulting in more cost-efficient scales of production (Krause and Mikkelsen 2017).

Figure 2: Sample illustration of a seaweed aquaculture co-location.

With the many potential economic and environmental positive externalities seaweed aquaculture can provide, the choice to incorporate seaweed aquaculture as a co-location activity within the CVOW lease area is realistic and justified[3].

2.2.2 Non-harvested Seaweed Forest

The option to plant a seaweed forest in the unused space within the CVOW lease area is another viable technique (Figure 3). Separate from seaweed aquaculture, the main benefit of planting a non-harvested seaweed forest is for the environmental and ecosystem implications. For many products, economic value is determined by those that benefit from it. A seaweed forest has additional non-market service values, that indirectly affect the population of Virginia (Kite-Powell 2017). In the case of a seaweed forest, ecosystem service values cannot be observed from prices in markets, but rather must be estimated by quantifying the ecological service produced and then applying a unit value (US EPA 2016). For instance, as previously discussed, one acre of seaweed can absorb about 8.27 tons of CO_2 and 161.87 pounds of N, annually (World Bank Group 2016). The tons of CO_2 and N absorbed by a seaweed forest each year would be the ecological service, and the environmental cost imposed by adding a ton of CO_2 and N to the atmosphere would

[3]Though seaweed aquaculture has a promising future as a co-location activity, this review would be incomplete without mentioning the potential permitting hurdles that would need to be overcome to establish an aquaculture farm within an OSW lease area. In a study comparing the stringency of environmental regulations across the world, it was found that the U.S. and Canada had the highest level of regulatory stringency, resulting in lower growth rates within the aquaculture industry (Abate, Nielsen, and Tveterås 2016). Permitting of an aquaculture area within the CVOW project would depend on U.S. Federal regulations because the CVOW farm is located within Federal waters. A marine monitoring plan would likely be required to limit the danger to marine species from the aquaculture activities.

be the unit value (Kite-Powell 2017). Monetary values are often assigned to ecosystem services as well. Published estimates from various studies of ecosystem service value from global marine environments vary from almost zero dollars to more than $100 million/year/square kilometer (Kite-Powell 2017). This means there is a monetary value associated with the capture of CO_2 and N from the environment. These estimations are dependent on the location, the specific values included, and assumptions used in each estimation (Kite-Powell 2017). The existing broad range of dollar values demonstrates to researchers that absorption of greenhouse gases by a seaweed forest should be assessed on a case-by-case basis to quantify the potential benefits provided by seaweed carbon sequestration. It is not in the scope of this research to quantify the value of carbon capture due to the co-location of a seaweed forest within the CVOW lease area, however, it is worth noting that there are monetary values associated with the capture of CO_2 and N from seaweed.

Seaweed forests are known to produce other ecosystem contributions besides the storage of CO_2 and N. It is widely recognized that marine species aggregate to structures in the ocean to develop reefs, and thus, are expected to aggregate to offshore wind turbines as well (Langhamer 2012). In a review of which co-location activities could potentially be compatible with OSW, Buck et al, (2017) noted that OSW turbines can provide protection and habitat for marine species. According to the MARCO Mid-Atlantic Ocean Data Portal, migratory fish species, turtle species (2-3 species above the average), conch, and migratory bird species are known to travel within the CVOW lease area (Mid-Atlantic Regional Council on the Ocean 2020). The environment within the lease area will be altered due to the installation of wind turbines and the seaweed forest could contribute additional food and habitat resources to some pelagic species (Leung and Yang 2012; Bailey, Brookes, and Thompson 2014).[4]

[4]Aside from contributing to greenhouse gas sequestration and providing ecosystem services, seaweed forests are known to offer storm-surge protection (Sheng, Lapetina, and Ma 2012; Bradley and Houser 2009). However, studies on the exact extent of the storm surge effects of seaweed are limited and depend on the intensity and speed of each storm; as well as the density, height, and width of the seaweed forest itself (Sheng, Lapetina, and Ma 2012). Based on current research, it is determined that the more vast and dense the forest, the more effective the forest is at providing storm-surge protection (Sheng, Lapetina, and Ma 2012; Bradley and Houser 2009). It is difficult to predict the level of storm surge protection provided by a seaweed forest within the CVOW lease area; however, this section of the literature review aims to deliver a comprehensive list of potential benefits seaweed forests are known to offer.

Figure 3: Sample illustration of a non-harvested seaweed forest.

It is important to include that the CVOW lease area does intersect with migratory routes of marine mammals and pelagic fish species (Mid-Atlantic Regional Council on the Ocean 2020). The introduction of foreign material such as ropes and moorings to create a seaweed forest presents a risk of pollution and entanglement of marine megafauna (Campbell et al. 2019; Benjamins et al. 2014). Ideally, the seaweed would begin growth on biodegradable ropes until the seaweed is dense enough to attach to the rock ruble surrounding the turbine monopoles on the seafloor. To avoid entanglement, it is advised that permitting authorities take extra precautions to ensure equipment is well designed before introduced to the marine environment (Campbell et al. 2019).

2.2.3 Designated Research Area

The final co-location activity included in this CE is a designated research area. A designated research area would prohibit public access and fishing but allow funded research projects to occur within a specified portion of the available ocean space within the CVOW lease area (Wenzel and D'lorio 2011). The intent of setting aside ocean space within the lease area is to offer scientists the opportunity to collect valuable scientific data on the impact of OSW farms on marine life. By forbidding public access to a portion of the lease area, the industry can research the effects of OSW turbines on the surrounding marine environment in absence of additional human impact. According to the National Marine Protected Areas Center, "research only" areas are often referred to and managed as marine reserves (Wenzel and D'lorio 2011). Throughout this section, the 'designated research area' co-location option may be interchangeably referred to as a 'marine reserve' because that is the terminology most frequently used in the literature.

Figure 4: Sample illustration of a designated research area.

A marine reserve by definition permits human access to an assigned zone and prohibits the "extraction or significant destruction of natural and cultural resources" within that zone (Wenzel and D'lorio 2011). The purpose, size, and management practices of marine reserves vary widely throughout the world depending on location, the local community, and the regulators (McCrea-Strub et al. 2010; Bartholomew et al. 2008; Suman, Shivlani, and Walter Milon 1999; Ashley et al. 2018). Implementation and management of a marine reserve within an OSW lease area should comply with local and federal regulations and policy (Ashley et al. 2018). The purpose of the designated research area described in this experiment is purely to provide marine researchers with ocean space to safely conduct innovative and informative investigations on the effects of OSW farms on the surrounding marine environment.

In addition to providing space for marine research, marine reserves are also known to foster aquatic biodiversity, which can support surrounding fisheries (Pauly et al. 2002; Bartholomew et al. 2008; White et al. 2008; Ashley et al. 2018). While biodiversity and supporting fisheries are not the main objectives of the designated research area in this experiment, it is important to discuss the potential positive externalities marine reserves could initiate. By disallowing extraction and degradation of marine species within a marine reserve, juvenile species are permitted to mature to adulthood causing a 'spillover' effect outside of the marine reserve into fishing areas (Halpern and Warner 2003; Howarth et al. 2015).[5] Data mapped within the MARCO Mid-Atlantic Ocean Data Portal

[5] It is worth noting that a "spillover" effect could occur in the seaweed aquaculture farm and seaweed forest areas as well since fishing would also be disallowed in those regions.

details which species are active in this region. The map shows sparse commercial fishing activity and moderate levels of recreational fishing and party-boat charters within the CVOW lease area. The map specifically details commercial fishing for herring and scallops, and the use of pots and traps within and in the region surrounding the lease area (Mid-Atlantic Regional Council on the Ocean 2020).

Literature indicates that research-only marine areas are sometimes met with tension among anglers and recreational boaters (Bartholomew et al. 2008). A study conducted on stakeholder perception of marine reserves in the Florida Keys found that anglers and recreationists worry about having access to ocean areas to pursue their endeavors (Suman, Shivlani, and Walter Milon 1999). To mitigate conflict and negative perceptions regarding the designated research area, it is advised regulators incorporate perspectives of local anglers and recreationists when designating marine reserves and making management decisions (Suman, Shivlani, and Walter Milon 1999). The main purpose of our research is to achieve exactly that by allowing the public to share which co-location activities they prefer to be coupled with the CVOW farm.

2.3 Review of General Positive Externalities Associated with Co-Location

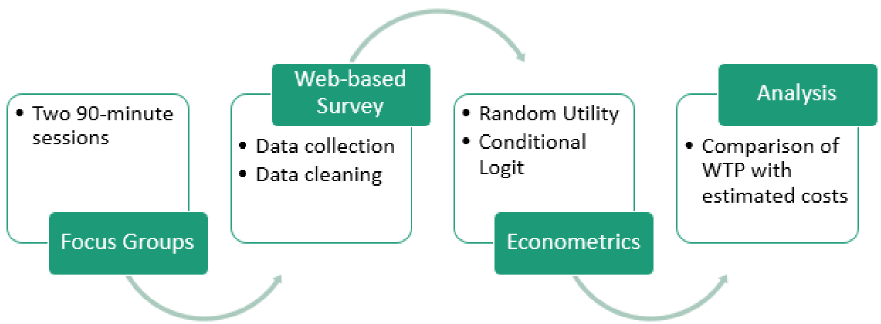
A known advantage of turning OSW farms into multi-use sites is the option to share operation and maintenance costs between activities. A study in the North Sea found that co-location of seaweed aquaculture with an OSW farm presents operation and management (O&M) cost savings opportunities, which are often referred to as synergy (van den Burg et al. 2016). Expert consultants involved in the case study, calculated that synergy can reduce shareable O&M costs of labor and transport by up to 10% (van den Burg et al. 2016). Achieving cost savings from co-location requires advanced planning between businesses. According to previous economic studies, it is unlikely for co-location to largely impact the fundamental economics of ocean spatial use, however, it can make marine endeavors more efficient in terms of marginal costs (Kite-Powell 2017). For example, aquaculturists, researchers, recreationists, and energy providers would economically benefit from aligning with ocean monitoring networks since these spatial planning systems have significant potential to serve as oceanic environmental quality monitoring stations (Buck and Langan 2017). Sharing oceanic data with other users can result in increased efficiency across enterprises.

Accompanying potential cost savings, co-location can optimize the use of marine space. Two activities co-located within the same leased space take up less ocean and habitat than they would as separate operations (Kite-Powell 2017). Multi-use sites provide benefits to the public by minimizing the total impacted space that is used for maritime businesses and providing ecosystem services such as carbon sequestration (Kite-Powell 2017). Co-location to save ocean real estate presents a public benefit in the form of avoided opportunity costs linked to ecosystem services by condensing human impact into one area (Kite-Powell 2017). There are various categories of ecosystem service values that are often displaced by maritime operations (Kite-Powell 2017). Some of those ecosystem service values include commercial and recreational fishing and boating. By consolidating marine activities to confined regions in the ocean, it is possible to become more economically efficient and to reduce the overall acreage of disturbed ocean habitat.

3. Research Methodology

Our approach to modeling the WTP for co-location activities with the CVOW project incorporates the use of focus groups, a web-based survey instrument, and random utility modeling (Figure 5). Lessons learned from the focus groups were integrated into the CE. Once the data was collected, random utility and conditional logit models were utilized to estimate public WTP. Finally, the calculated WTP values were compared to estimated costs of implementation and maintenance of each co-location activity to determine which combinations of activities are most viable according to our data set.[6]

Figure 5: Research Methodology Process



3.1 Study Area

The CVOW project is the first OSW farm in U.S. Federal waters and the first wind farm directly off the coast of Virginia. A pioneering project such as the CVOW farm typically paves the way for complementary opportunities, which may require the support of the public. Qualtrics professional survey services were hired to collect data from a representative sample of adult Virginia residents with a demographic profile that matches U.S. Census information. There are currently no existing CE studies examining Virginia consumer WTP for co-location activities with the CVOW farm.

3.2 Focus Groups

To assist with developing the web-based survey, two focus groups were conducted virtually, via Zoom video conferencing in December 2020. The purpose of conducting focus groups was to gain insight on and assess the perception of co-location activities, to inform the survey instrument before dissemination. The first focus group consisted of five adults (18 years or older) Virginians who had some level of industry knowledge related to coastal topics such as renewable energy, fishing, aquaculture, or marine resource management. These participants were recruited from Virginia Sea Grant's list of

[6] The materials associated with the research methods involved in this study (ID # 20-580) complied with and were approved by Virginia Tech's (VT) Institutional Review Board (IRB) to ensure the safety of all participants (Appendix A).

industry contacts, Virginia Tech's Center of Coastal studies, and the research team's professional connections. The second focus group consisted of nine adult members of the public whose occupation is not directly related to offshore wind and marine topics. The participants in the second focus group were recruited via personal and professional connections of the research team who reside in varying regions throughout the Commonwealth of Virginia.

Each focus group session lasted 90 minutes during which, participants were asked open-ended questions about their current level of knowledge of the CVOW farm, their relationship to the ocean, and ocean-related activities (i.e., experience boating, fishing, and seafood consumption), and their perspectives on various co-location techniques. Participants were compensated $40 for their time and opportunities for breaks were provided throughout both sessions.

Contributors interacted with one another in each session and discussed their experiences with ocean-related activities and offshore wind. Participants watched a brief PowerPoint presentation consisting of a combination of narrative and visual aids, to assist the participants with understanding more about the CVOW project and envisioning each of the three compatible co-location activities. The PowerPoint presentation was generated to provide unbiased, clear, and concise information on the CVOW project and the implications of each co-location activity. Following the presentation, each group participated in an activity during which they were asked to demonstrate their preferences for the co-location activities.

After discussing each co-location activity, the participants were shown a combination of co-location techniques that occupy certain percentages of available ocean space within the CVOW lease area. Each participant was then asked to create their ideal combination of co-location activities at their desired levels (in the form of percentages). During the discussion, participants were permitted to choose a "Status Quo" (SQ) option in which none of the three co-location activities are incorporated with the CVOW farm and public access is the only activity that occurs between the turbines. Following choice experiment theory, participants must be offered a consistent SQ option in which they can opt for baseline conditions (Moeltner et al. 2021). Following their choices, participants were asked to declare the most they would pay to see their preferred option realized. Contributors were permitted to opt out of an annual tax and verbally discuss how they arrived at their choice and payment decisions. The purpose of the annual tax was described to participants as necessary for the implementation and management costs of each activity.

Moderation of focus group sessions adhered to best practices by fostering free-flowing discussion, the inclusion of all participants, abstaining from technical jargon, and emphasis on experiences of participants related to the research topic (Nyumba et al. 2017; Edmunds 1999). The focus group protocol is available in Appendix A. Overall, the first focus group session demonstrated interest in the SQ operations, while the second session expressed a desire for co-location activities and a WTP for such. Insights gathered from the focus groups were incorporated into the survey instrument; specifically relating to the bid range for annual taxes, and the specific co-location activities represented in the survey.

3.3 Stated Preference Choice Experiment Theory

Given the hypothetical nature of the experiment and the objective of eliciting marginal values for attributes of a differentiated good (the co-location mix), the best way to collect WTP data is through a stated preference choice experiment (CE). CEs, by nature, assume individuals will choose options that will maximize their utility subject to budget constraints. Some services offered by co-location activities such as carbon and nitrogen storage increased opportunities for local seafood, and research findings are not directly for sale, so it can be difficult to quantify a consumer's preference for each service. By assigning a price to each choice, the survey responses can be used in nonmarket valuation calculations to determine WTP values for each form of co-location.

A primary motivation behind decision-making during a CE is the price (herein also referred to as the "bid" or "tax") associated with each choice. Individuals make decisions based on budget constraints. Although a participant might prefer a co-location option, they may choose the zero-cost, SQ option simply because their household budget does not allow them to choose otherwise.

3.4 Survey Design

Through the incorporation of literature, focus group information, and collaboration with industry professionals, the final CE included three co-location activities, the SQ operations, and four different annual tax levels. Chapter 5 of "A Primer on Nonmarket Valuation," among other sources, was applied as a guideline for the experimental design procedures to compose this survey (Holmes, Adamowicz, and Carlsson 2017). The following sections of this paper describe the rationale behind the chosen attribute levels and the survey design procedures.

3.4.1 Attributes and Attribute Levels

To compose a CE, it is essential to define each attribute and associated levels that will be displayed to survey takers. Field research and literature reviews helped determine the five attributes that would be available at four levels throughout the survey. The full factorial design, which combines all four levels of all five attributes, ensures that all main and interaction effects between attributes are statistically independent when estimating a model (Hensher, Rose, and Greene 2015). With four co-location attributes and an annual tax, at four levels, there were 1,024 possible combinations of attributes (4x4x4x4x4=1,024). MATLAB was used to determine the full factorial design of choices with our specific attributes and attribute levels. The four levels for each co-location activity were represented as percentages of available acreage within the CVOW lease area. The fifth attribute was the annual tax associated with each option and was represented by four uniformly spaced dollar values. These taxes were based on researched and estimated costs of implementation and management of each co-location activity. According to CE theory, the alternatives within choice experiments should be presented in the form of matrices with alternatives as the columns and attributes as the rows to produce a panel of discrete choice responses (Holmes, Adamowicz, and Carlsson

2017; Scarpa and Rose 2008). After eliminating nonsensical combinations of attributes and levels (i.e. combinations which exceeded or fell below 100%, or that set "public access" to 100% (thus replicating the SQ option) there were a total of 64 unique permissible profiles (specific combinations of attribute settings). These were then grouped into 40 unique choice sets following a D-efficiency design criterion (Holmes, Adamowicz, and Carlsson 2017), each comprising two different co-location scenarios, plus the (invariant) SQ option of 100% public access at no additional cost.

To reduce the possibility of survey fatigue, each respondent was randomly shown four independent choice sets (a sub-set of four choice sets is referred to as a “choice block”). In total, the survey included ten different choice blocks, with each administered to a sub-sample of respondents of approximately equal size. Figure 6 represents an example of a choice set that was incorporated in the survey. Appendix B displays all 40 choice sets utilized in the survey instrument.

In summary, Attributes and attribute levels that were included in the survey are as follows:

- Co-location activity (Seaweed Aquaculture, Seaweed Forest, Designated Research Area, Public Access [SQ]
- Co-location Activity Levels (0%, 25%, 75%, 100%)
- Annual Tax Levels for Co-location Options ($1, $6, $11, $16)
- The Status Quo (SQ) Option (100% Public Access, $0 Annual Tax)

Participants were then asked to assume there were 1,000 acres of available lease area for the incorporation of co-location activities and that co-location activities were mutually exclusive. For example, if a choice set designated 75% of the open 1,000 acres as a research area, that would mean the research area occupies 750 acres and other activities would be prohibited within that same 750 acres.

Figure 6: Example of a choice set provided in the web-based survey.

Co-Location Activity	Option A	Option B	Option C
Seaweed Aquaculture	100%	75%	0%
Non-Harvested Seaweed Forest	0%	25%	0%
Designated Research Area	0%	0%	0%
Public Access (Status Quo)	0%	0%	100%
Annual Tax per Virginia Household	$6	$11	$0

Important precautions were followed to ensure the high quality and efficiency of the survey design to elicit reliable responses as suggested by Johnson et al. (2017), Champ et al. (2017), and Scarpa et al. (2008). For example, each choice set was evaluated to safeguard against dominant options (i.e., there were no choice sets in which two options displayed the same combination of attributes and levels with differing bids). To elicit reliable responses, descriptions of attributes were displayed in non-technical language and clear and concise directions were provided in the survey instrument. To mimic realistic and binding decisions for each respondent, we stressed that this data would be shared with regulators and industry professionals who may utilize the results of this study, and requested respondents vote as if their household would incur the cost associated with each option.

3.4.2 Survey Instrument Implementation

Overall, the survey consisted of a combination of narrative and visual techniques to describe necessary information to the respondents to assist with making informed decisions. Visual techniques consisted of maps created with ArcGIS and images obtained using various internet sources. Photographs of co-location activities assisted the survey respondents in visualizing co-location scenarios. The survey was designed in a manner that provided the necessary information for the consumer to make a choice that will maximize their utility.

Upon entry into the survey, respondents were supplied with a section consisting of background information regarding the CVOW farm and the U.S. offshore wind industry. It then asks respondents if they were previously aware of the CVOW farm and the currently active CVOW two-turbine pilot study. The remainder of the first section supplied information and implications associated with each co-location activity.

The second section of the survey asks the respondents to make four main assumptions when answering choice questions. The first is to make choices as if they would be incurring the costs associated with the choice sets; the second is to vote as they would in a public election; the third is to assume all co-location activities will not overlap in the open ocean space; the fourth is to treat each choice set as a new vote and not make decisions based off the previous choice sets. The fourth assumption is important for reducing potential sequencing effects in the survey responses often caused by allowing earlier choices to influence later votes for subsequent choice sets (Johnston et al. 2017; Moeltner et al. 2021).

To further reduce sequencing effects, we rotated choice sets within each block for sub-sets of respondents that were assigned to the same block, ensuring all four choice sets had an equal opportunity to be seen first throughout the entire sample. By implementing these measures in the survey design phase, we were afforded the option to execute our econometric models utilizing only the first vote for each respondent. Additionally, in section two of the survey, respondents are reminded that there are valid reasons for selecting various co-location scenarios and the SQ option. By highlighting justifications for each decision that can be made, we reduced unintended predisposition towards certain choices which aligns with best practices in contingent valuation research (Mitchell and Carson 1989; Moeltner et al. 2021). To ensure participants voted in line with personal financial abilities, we stressed that any income that went towards a co-location option would reduce available income for other uses. By explicitly addressing this consequence, we align with CE best practices to induce financial discipline in decision-making (Johnston et al. 2017; Moeltner et al. 2021).

In the third section of the survey, respondents are shown four choice sets pertaining to a specific choice block. To continue through the survey, respondents were required to choose either option A, B, or C for each choice set to collect a total of four votes from each individual. During the survey, participants were asked to answer questions on behalf of their household. Depending on the responses to the four choice sets, respondents were shown one of two follow-up questions. Those who chose the SQ, option C, on all four occasions signal the possibility that their votes are not based on the scientific information provided in the survey and may not have considered the benefits and costs associated with each scenario. Those individuals received the first follow-up question to help us better understand if the response is considered a “protest vote” which can bias the economic values estimated in this study (Meyerhoff, Bartczak, and Liebe 2012; Moeltner et al. 2021). Protest responses were flagged based on their follow-up question answers, which reflected opinions that the co-location activities are (1) not scientifically feasible,

(2) that co-location activities should be funded by the government with existing taxes and fees, and/or (3) that the individual believes their household already pays enough taxes.[7]

The final section of the survey consisted of a set of questions requesting the respondents' perceptions of the quality and helpfulness of the background information, the ability to make their own decisions, and whether they felt pressured to choose any one co-location option. Additionally, these questions assist us in identifying protest votes and detecting observations that are suitable for econometric observation by understanding if the requested assumptions were made by individuals during the CE (Moeltner et al. 2021). Following the survey quality questions, the study collected general demographic information such as household size, ZIP code of residence, education level, and income category. See Appendix B for the full survey.

Qualtrics utilizes "opt-in panels" to recruit survey respondents. In the contract associated with this research, Qualtrics was instructed to collect a sample size representative of the Virginia population. Participants were required to be at least18 years of age and Virginia residents (discussed in detail in section 5.1 Survey Response). After a pretest of 50 survey responses in February 2020, minor grammatical and survey execution corrections were made to ensure the survey was properly received by participants. According to pretest responses, clarity of the background information and instructions was determined adequate, the survey length was reasonable, and the annual taxes associated with each choice were realistic.

The final survey instrument was initiated by Qualtrics on February 15, 2021 and closed when the targeted population size and demographics were collected, on March 12, 2021. In accordance with VT IRB requirements, each participant was obligated to agree to an informed consent form before beginning the survey. Upon receiving a total of 1,479 responses, the data set was cleaned of nonsensical, vulgar, and incomplete responses which reduced the sample size to 1,037 complete responses.

4. Econometric Models

The driving theoretical concept behind this research is random utility maximization (RUM) theory.

4.1 Random Utility Maximization

RUM theory assumes that given a set of alternative options, an individual will choose the option which provides them with the highest utility or benefit (Holmes, Adamowicz, and Carlsson 2017). McFadden (1974) established the RUM approach which has become a foundation for economic valuation through choice experiments (McFadden 1974).

Utility (U) is commonly characterized by the individual's (i) preference for an alternative (j) in a choice set. Remember, choice alternatives in this experiment consist of co-

[7]Respondents were shown the second follow-up question if at least one of their four votes was for a co-location option (A or B).

location option A; co-location option B; and the status quo (no cost) option C. General utility for a given individual is expressed in Equation 1 as:

Equation 1

$$U_{itj} = z_{itj}\theta + \lambda\ (m_i - P_{itj}) + \varepsilon_{itj}$$

$$\varepsilon_{itj} \sim \text{EV}\ (0{,}1)$$

where vector z_{itj} includes the co-location scenario attributes, m_i is annual income, P_{itj} is the annual tax associated with the co-location scenario, and ε_{itj} captures all other components that affect the utility but are not visible. The RUM utility function for individuals who choose the status quo (SQ) option, which stipulates "100% public access" is given in where z is a binary indicator for SQ (option C) with θ capturing the corresponding constant term. Additionally, P equals zero in the SQ scenario and thus, is not included in the RUM of those who choose the SQ option.

In a RUM model, a certain choice can be explained only up to the probability of an alternative being chosen (Krueger, Parsons, and Firestone 2011). If the errors align with a Type-I Extreme Value distribution and are independently and identically distributed, the probability of individual (i) selecting option (j) on a given occasion (t) is expressed as:

Equation 2

$$prob\ (y_{itj} = 1) = \frac{exp\ (x'_{itj}\beta)}{\sum_{j=1}^{J} exp\ (X'_{itj}\beta)}$$

$$x_{itj} = [z'_{itj}\ P_{itj}]',\ and\ \beta = [\theta' - \lambda]'$$

for which, y_{itj} is a binary indicator that takes the value of 1 if an individual chooses j on the t^{th} occasion, and a value of zero if otherwise (Moeltner et al. 2021).

The sample likelihood for $i = 1 \ldots N$ independent individuals, each facing T independent choice occasions involving J alternatives is then given by Equation 3.

Equation 3

$$\text{P}\ (\text{y}|\ \beta\ , \text{X}) = \prod_{i=1}^{N}\prod_{t=1}^{T}\prod_{j=1}^{J} \left(\frac{exp\ (x'_{itj}\beta)}{\sum_{j=1}^{J} exp\ (x'_{itj}\beta)}\right)^{y_{itj}}$$

4.2 Model Specification

A crucial characteristic of a conditional logistic (CL) model is that there is a constant zero-cost, SQ option provided in each choice set viewed by respondents and that alternatives are hypothetical (Holmes, Adamowicz, and Carlsson 2017). Providing a zero-cost, SQ option is how indirect utility of non-participation or non-purchase respondents is captured in our model (Moeltner et al. 2021). As a reminder, current operations within the CVOW lease area are 100% public access at no extra cost to the consumer, which is the reason the SQ option sets the price attribute to zero and other attributes to fixed values. The chosen CL model consists of nonlinear main effects and three linear interaction terms. The *clogit* command in Stata was utilized to execute the conditional logit regression.

4.3 Willingness-to-Pay Estimation Model

Expected willingness-to-pay (WTP) w_i for a given individual to obtain a specific co-location scenario with given attributes z_p is derived implicitly by equating the observed portion of indirect utility for the SQ at full income m_i with the observed portion of indirect utility associated with either option A or B co-location scenarios and reduced income m_i - w_i (Moeltner et al. 2021). Essentially, the maximum amount the individual is willing to trade-off for a given co-location scenario is w_i. By separating β into a sub-vector β_z that corresponds to co-location shares, and the SQ coefficient β_{SQ}, expected WTP is calculated using Equation 4.

Equation 4

$$w_i|\mathbf{z}_p, \boldsymbol{\beta} = \frac{1}{\lambda}\left(\mathbf{z}_p'\boldsymbol{\beta}_z - \beta_{SQ}\right)$$

Due to the error terms following a logistic distribution with a zero-mean and unity scale of 1, this model estimates the mean WTP. The *nlcom* command in Stata is applied to obtain WTP predictions for co-location scenarios along with confidence intervals. Expected WTP is dependent upon the estimate of λ, which is the marginal utility of income. This command uses the Delta method which generates asymptotic standard errors and confidence intervals. A smaller λ will increase mean WTP. For instance, if many people choose co-location options (A or B) in the questionnaire, even at the highest tax provided, this suggests a relative small marginal utility of income, leading to a small estimate of λ. This explains how WTP estimates can surpass the tax values offered in the survey. The SQ interaction variable in the *nlcom* model captures the implicit utility of the SQ option.

5. Results

5.1 Survey Response Statistics

The survey generated 1,037 complete responses, which exceeded our target of 1,000 responses. After removing flagged protest responses (108) and responses that had unrealistic answers (95) to general demographic questions, our sample size was reduced to 838 useful questionnaires. With each contributor providing four votes, this provides a sample of 3,352 observations for economic analysis. General demographics of the 838 respondents are given in Table 1. As visible in the table, our sample of respondents largely reflects population demographics from the U.S. Census, with slight differences in the allocation of some demographics. Our sample has a somewhat larger number of females, individuals in the 18 to 24 age group, 25 to 34 age group, 35 to 44 age group, and higher portions of parties with an annual income of less than $50,000.

Table 1: General Demographics

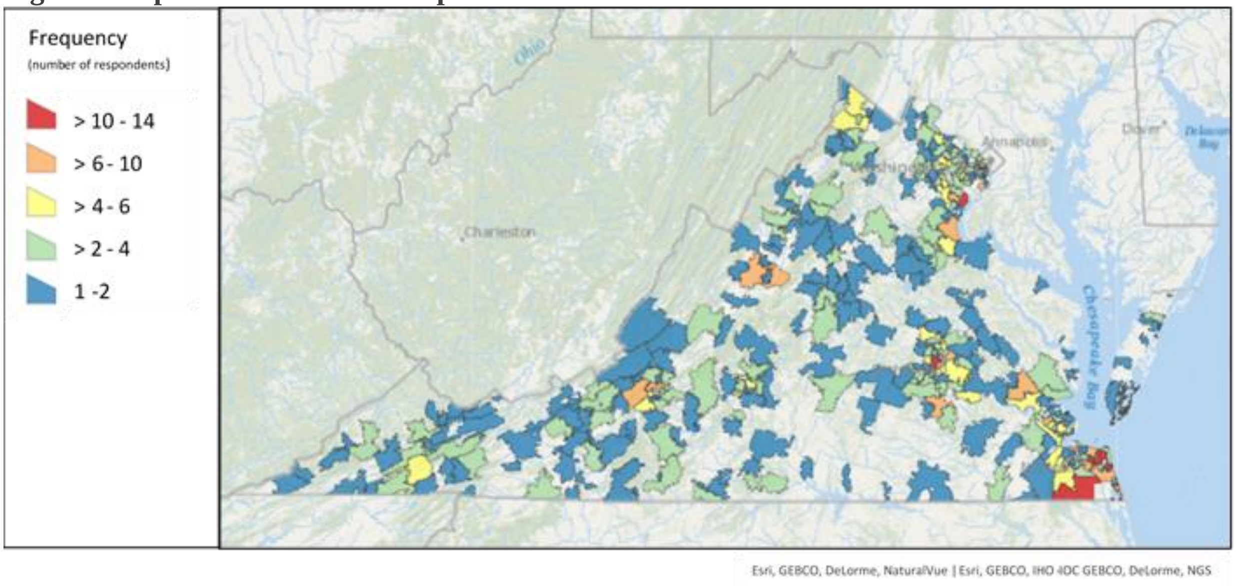
Demographic	%	Mean	Std.	Min	Max	Obs.	Census
Respondent-Specific							
female	67.42%					1,037	52.15%
non-binary/prefer not to say	1.55%						N/A
age		43.51	17.57	18	87	1,037	
18-24	19.33%						11.40%
25-34	20.76%						18.12%
35-44	20.64%						17.66%
45-54	13.01%						18.81%
55-64	13.37%						16.47%
65+	12.89%						17.54%
Less than HS Diploma	4.78%					1,037	11.52%
HS/GED	2339.00%					1,037	25.46%
Some college	28.04%					1,037	21.90%
AD / 2-yr college	8.83%					1,037	70.70%
BD / 4-yr college	20.41%					1,037	20.20%
MS, PhD, Prof.	14.56%					1,037	13.86%
years of VA residency						1,033	N/A
0-5	9.87%						
5-10	8.88%						
10+	81.30%						
HH-Specific							
HH income <50K	42.60%					1,037	40.00%
50K-99.999K	31.86%					1,037	30.00%
100K-149.999K	15.04%					1,037	16.00%
150K-199.999K	6.44%					1,037	7.60%
>=200K	4.06%					1,037	8.90%
HH size		2.93	1.56	1	14	1,037	N/A
family members under age 7		0.35	0.79	0	8	1,037	N/A
family members 7-18		0.65	1.17	0	12	1,037	N/A

N = 1,037

Survey takers were also asked how many years they have been Virginia resident and their zip code of residence. Figure 7 displays the distribution of survey respondents based on zip code. Of all respondents (N = 1,037), 1,033 individuals provided the number of years they have lived in VA. Of the responses, almost 10% have lived in VA for 0-5 years, approximately 9% have lived in VA for 5-10 years, and 81% have been VA residents for

10+ years. This information demonstrates that most of our respondents have long-term experience living in VA and may have a vested interest in the success of the State's economy.

Figure 7: Zip code distribution map



The survey asked respondents about their familiarity with the CVOW project and the two-turbine pilot study to help gauge sample knowledge of local offshore developments. Approximately 62% of respondents were unaware of the CVOW project before reading the information provided in the survey, while 72% were unaware of the active two-turbine pilot study prior to reading the information provided in the survey.

Table 2: Awareness of CVOW and Pilot Study

Activity	yes	no
	% of respondents	
CVOW Project	37.51%	62.49%
Two Turbine Pilot Study	27.77%	72.23%

N = 1,037

Of all 1,037 respondents, 899[8] individuals chose either co-location scenario A or B on at least one occasion. Those individuals were shown a corresponding follow-up question, to assist in characterizing their rationale behind their vote.[9]

[8]812, excluding protest no, and unreliable follow-up responses.
[9]Individuals were permitted to select as many reasons as applicable.

Inversely, 138[10] respondents chose the SQ option for all four votes. These respondents viewed a separate follow-up question in which these respondents chose the following reasons behind their votes: “Any form of co-location should be provided by local/state governments at no cost to local residents” (5.69%), “the co-location activities displayed in the questions were not worth the cost to me and my household” (3.95%), “I do not live close enough to the coast to benefit from co-location” (4.44%), “my household is already paying plenty of taxes and fees - these should be enough to cover the co-location activities” (7.81%), “my household simply can't afford to pay for the co-location activities at this time” (4.34%), “I / my household often spend time in the ocean/boating, and we prefer unlimited access” (1.35%), and “I do not believe one or more of the co-location options to be scientifically feasible” (2.12%). Lastly, 1.83% chose the “Other” option as reasoning for their response.

Finally, respondents were also asked to answer Likert-scale questions to gauge the clarity and validity of the survey. As demonstrated in Table 3, a majority of respondents either “strongly agree”, “agree”, or “somewhat agree” that the survey was sufficient, easy, and fair; and respondents voted as if the price impacted their choice, and their vote was real. This data further validates our responses because participants understood the survey and felt they could make informed decisions

[10]There was a total of 26 respondents who chose the SQ option for all 4 votes after excluding protest no, and unreliable follow-up question responses.

Table 3: Clarity and Validity Check Questions

	strongly agree	agree	somewhat agree	neither	somewhat disagree	disagree	strongly disagree
survey information/complexity:							
survey provided enough information	41.27%	32.98%	14.85%	8%	1.54	0.58%	0.77%
information in the survey was easy to understand	36.26%	32.88%	15.24%	10.22%	3.57%	1.35%	0.48%
information in the survey was fair and balanced.	33.94%	33.75%	14.95%	10.22%	2.60%	0.87%	0.58%
voting realism/consequentiality:							
price impacted choice	25.84%	23.43%	19.29%	18.80%	5.50%	4.53%	2.60%
choice questions were easy to answer	39.25%	30.86%	16.30%	9.45%	2.80%	0.87%	0.48%
would vote in the same way on a public vote or referendum	38.48%	33.65%	12.63%	12.92%	1.35%	0.39%	0.58%
voted as if the costs were real	41.95%	31.44%	11.96%	10.90%	1.83%	1.35%	0.58%
perceived concern:							
descriptions provided were sufficient for informed choices	33.75%	36.45%	14.85%	11.28%	2.41%	0.39%	0.87%
survey let me make up my own mind	40.69%	33.46%	13.79%	8.87%	1.64%	0.77%	0.77%

N = 1,037

5.2 Estimation Results

The final estimation results include 838 complete questionnaires which exclude the "protest no" and unreliable responses. Within the CL model, attributes were expressed as binary indicators, which allows for nonlinear attribute effects, while the tax associated with each option was treated as a single continuous regressor, (Moeltner et al. 2021; Holmes, Adamowicz, and Carlsson 2017; Hensher, Rose, and Greene 2015). CL estimation results are available in Table 4. As mentioned in section 3.4.2 Survey Instrument Implementation, due to the lack of sequencing among the four responses per individual, we are also able to use only the first vote for every individual. These results can be viewed in columns five through seven in Table 4. The table provides the coefficient, standard deviation, and z-score for the CL regression. Apparent in the regression results are highly significant z-scores (>1.96), which indicates that the estimates are assessed with high efficiency (relatively little error noise). It is evident in the table that the SQ variable has a negative coefficient for both models and estimates only vary slightly when using only the first vote. These observations suggest an absence of sequencing, which means respondents contemplated each choice set independently.

Table 4: Conditional Logit Estimation Results

	all 4 sets			first set only		
variable	**Coef.**	**std.**	**z**	**Coef.**	**std.**	**z**
SQ	-0.151	0.165	-0.92	-0.327	0.340	-0.96
aqua = 25%	0.873	0.138	6.31	0.825	0.282	2.93
aqua = 75%	1.145	0.191	5.99	1.127	0.389	2.89
aqua = 100%	0.867	0.192	4.53	1.100	0.392	2.81
swfor = 25%	0.752	0.140	5.37	0.732	0.291	2.51
swfor = 75%	0.918	0.194	4.73	0.811	0.400	2.03
swfor = 100 %	0.851	0.191	4.45	0.927	0.391	2.37
dra = 25%	0.668	0.140	4.77	0.588	0.286	2.05
dra = 75%	0.924	0.184	5.01	0.867	0.377	2.3
dra = 100%	0.680	0.193	3.52	0.670	0.389	1.72
Annual Tax (bid)	-0.043	0.004	-10.3	-0.045	0.008	-5.39

all 4 sets = full sample with all 4 votes (N = 838, n = 3,352)
first set only = first vote (N = n = 838)
std. = standard deviation
z = z-score

After interpreting the coefficients in both models, it is clear, that the marginal WTP for a particular co-location activity is maximized at 75% seaweed aquaculture. Looking at the coefficients for all four sets, individuals are willing to pay $1.145 to increase seaweed aquaculture acreage from zero acres to 750 acres and $0.87 to increase seaweed aquaculture acreage from zero acres to 250 acres. This implies that the public values the extra 500 acres of seaweed aquaculture at $0.30. When comparing the increase of seaweed aquaculture from 75% to 100%, there is a loss of about $0.28. When assessing the coefficients for both the seaweed forest and designated research area activities, 750 acres is also the most preferred amount for those activities. In contrast to the seaweed aquaculture preferences however, marginal WTP is greater for 1,000 acres of both activities than 250 acres for both activities.

Both models (all four sets and first set only) indicate a small marginal utility of income with negative bid coefficients close to zero. The negative coefficient associated with the SQ variable indicates the public generally prefers any option over the SQ. This displays an overall desire for diversity among co-location activities.

5.3 Willingness-to-Pay Results

Utilizing the *nlcom* command in Stata, the estimated coefficients from the *clogit* regression were combined with all possible combinations of attributes and attribute levels to generate estimated WTP values for each scenario (Moeltner et al. 2021). Results for both models (all four sets and first set only) are represented in Table 5. The mean is the expected WTP over the entire sample. The high and low values are the upper and lower bounds of the confidence intervals from the command output. Due to the smaller sample size in the reduced model, the high and low ranges are larger, but the mean WTP values are comparable to the model using the full sample. The results from the full model including all four votes are the preferred estimation that will be discussed in detail for the remainder of this paper.

It was deduced from the econometric examination that the average Virginian household is willing to pay nearly $40 annually for the combination that includes all four co-location activities. The desire for variety among co-location activities suggests those who participated in this experiment are information seekers and want to experiment. Due to the lack of precedents for co-location in VA, this preference is anticipated. The second highest WTP amount is for the combination which includes 75% seaweed aquaculture and 25% non-harvest seaweed forest at more than $31. Willingness-to-pay for the SQ scenario (100% public access for zero dollars) decreases to less than $4 across households. On average, WTP was lower when public access was represented in a scenario.

Table 5: WTP Estimation Results (Annual $'s per HH)

co-location scenario (%)				all 4 sets			first set only		
aqua	**swfor**	**dra**	**pub**	**Mean**	**Low**	**High**	**Mean**	**Low**	**High**
25	25	25	25	39.50	32.21	46.80	40.17	25.87	54.47
75	25	0	0	31.19	25.11	37.27	34.64	22.07	47.22
25	75	0	0	28.73	22.92	34.55	29.68	18.24	41.11
75	0	25	0	28.92	23.22	34.62	30.69	19.12	42.26
25	0	75	0	28.56	22.98	34.14	30.17	18.94	41.40
0	75	25	0	21.67	16.63	26.71	22.62	12.57	32.67
0	25	75	0	23.77	18.51	29.03	27.06	16.31	37.82
75	0	0	25	30.04	24.10	35.98	32.40	20.46	44.33
25	0	0	75	23.74	18.70	28.78	25.66	15.37	35.96
0	75	0	25	24.77	19.40	30.14	25.35	14.87	35.83
0	25	0	75	20.94	15.97	25.90	20.39	10.20	30.58
0	0	75	25	24.93	19.66	30.20	26.60	16.08	37.12
0	0	25	75	18.99	13.92	24.07	23.59	13.65	33.52
0	0	0	100	3.51	-3.92	10.93	7.29	-7.40	21.98
100	0	0	0	23.60	18.08	29.12	31.79	19.30	44.28
0	100	0	0	23.22	17.81	28.63	27.93	16.65	39.22
0	0	100	0	19.27	14.09	24.45	22.21	12.07	32.35

all 4 sets = full sample with all 4 votes (N = 838, n = 3,352)
first set only = first vote (N = n = 838)
mean = mean WTP over all participants
low/high = lower/upper bound of 95% confidence interval.

It is expected that these values can be utilized by regulators and energy providers to compare implementation and management costs of each of the co-location activities to understand if incorporating these activities with the CVOW farm is economically viable. Due to the annual nature of the taxes, as made clear in the survey, the WTP values can be discounted and applied to future years.

6. Discussion

While cost-effectiveness, management, and implementation strategies are out of the scope of this study, one of the goals of this research is to inform offshore development managers about potential co-location opportunities with the CVOW farm in the context of VA public willingness-to-pay. Rough estimations of costs for each co-location activity were calculated to assist with comparing implementation and management costs to the WTP estimates. The subsections of this discussion provide further detail and support for each cost estimate and compare those estimates with the dollar per 1,000-acre value calculated from the survey responses.

6.1 Co-Location Activity Cost Estimates

The estimated cost of initial implementation and operation for each co-location activity were computed to serve as comparisons for the estimated WTP values calculated from this study. The cost estimates for each activity are based on presently known and available costs associated with seaweed aquaculture farms, man-made seaweed forests, and marine research areas. The implementation, operation, and enforcement costs of seaweed farms, seaweed forests, and designated research areas will vary depending on location, size, policy, and other unforeseen factors. It should be noted that the cost estimates in this study are approximated based on available information. Table 6 is a cost comparison table for all co-location activities and the estimated WTP values.[11]

6.1.1 Seaweed Aquaculture Cost Estimate

A regenerative ocean farming company that cultivates seaweed in the Atlantic Ocean estimates the market entry costs of a 20-acre offshore seaweed farm at $50,000 (Laylin 2015). This estimation includes costs associated with buying the materials and leasing ocean space to grow the crop. A study calculating maintenance costs for the operation of a seaweed farm in the North Sea approximated an annual cost of $203.50 per acre (van den Burg et al. 2016). This annual maintenance calculation included fixed, maintenance, harvesting and transport, labor, material, and other variable costs associated with the business.

To calculate a conservative annual cost per acre, the start-up and maintenance values were aggregated to produce an annual dollar per acre expense of $2,703.49 (Laylin 2015; van den Burg et al. 2016). When the expenses are divided by the Census Bureau’s number of households in Virginia (3,128,415), the annual cost per 1,000 acres[12] per

[11]The detailed cost estimate calculations and sources for each activity are in Appendix C.
[12]The number of acres assumed in the CE.

household is $0.86 (“U.S. Census Bureau QuickFacts: Virginia” 2020). Costs associated with regulation of an offshore seaweed farm by local United States government officials and the Virginia Port Authority are additional fees potentially associated with this co-location technique that was not readily available to include in this estimation.

6.1.2 Non-Harvested Seaweed Forest Cost Estimate

Valuing a non-harvested seaweed forest is comparable to valuing the start-up costs associated with the seaweed aquaculture farm. GreenWave ocean farming estimates that a 20-acre seaweed farm costs approximately $50,000 (Laylin 2015). This estimation includes permitting and material costs associated with setting up the rope systems in the water. As previously discussed in section 2.2.2 Non-harvested Seaweed Forest, the seaweed forest would most likely be introduced via biodegradable rope systems until the seaweed attaches to the rock rubble associated with the turbine monopoles. The seaweed forest would require maintenance in the early stages of the project to ensure the safety of marine species and the success of the endeavor.

Due to the lack of data on comparable man-made seaweed forest ventures, this study will assume the same annual start-up cost as the seaweed aquaculture farm. The same source was used for the maintenance costs; however, the harvesting price was subtracted from the annual maintenance costs, as the seaweed will not be harvested. The annual expense associated with a 1,000-acre seaweed forest is $0.81. Due to lack of harvesting and eventual self-sustaining growth, a seaweed forest would likely have lower long-term maintenance costs than an aquaculture farm. Once the forest is established and ropes are removed the seaweed forest may require infrequent management.

6.1.3 Designated Research Area Cost Estimate

As stated in section 2.2.3 Designated Research Area, designated marine research areas are commonly referred to in policy and literature as marine reserves. Research on implementation, operation, and management costs associated with marine reserves provided the values used to calculate the estimated price for comparison. According to an analysis evaluating expenditures of marine reserves across the world, a marine reserve of similar size to the CVOW lease area costs approximately $849.72 per acre to implement and maintain (McCrea-Strub et al. 2010). This puts the cost per 1,000 acres, per household at $0.27. Costs for marine reserves vary widely across the globe. While Virginia does have wildlife refuges in the state, there is an absence of active marine reserves in Virginia waters at the time of this study. The operation and maintenance costs associated with a marine reserve in VA may differ from the value utilized in this estimation.

6.2 Willingness-To-Pay Comparison

An implementation and management cost estimate was not calculated for the public access co-location activity because this study assumed that public access is the SQ, and Virginians will not be taxed extra to access this region. Management of public access within an offshore wind farm will come at a cost to regulators and the utility company to ensure public safety.

Table 6: Estimated Cost vs WTP Comparison

co-location scenario (%)					
Seaweed Aquaculture	**Seaweed Forest**	**Research Area**	**Public Access**	**Estimated Cost**	**Public WTP***
25	25	25	25	$0.49	$39.50
75	25	0	0	$0.85	$31.19
25	75	0	0	$0.82	$28.73
75	0	25	0	$0.71	$28.92
25	0	75	0	$0.42	$28.56
0	75	25	0	$0.68	$21.67
0	25	75	0	$0.41	$23.77
75	0	0	25	$0.65	$30.04
25	0	0	75	$0.22	$23.74
0	75	0	25	$0.61	$24.77
0	25	0	75	$0.20	$20.94
0	0	75	25	$0.20	$24.93
0	0	25	75	$0.07	$18.99
0	0	0	100	---	$3.51
100	0	0	0	$0.86	$23.60
0	100	0	0	$0.81	$23.22
0	0	100	0	$0.27	$19.27

N = 838, n = 3,352
Estimated Cost = rough implementation and maintenance estimate (see Appendix C)
Public WTP = WTP value for 25% = 250 acres, 75% = 750 acres, 100% = 1,000 acres
*WTP values are calculated using all 4 votes.

7. Conclusion

The co-existence of OSW farms and current marine activities is crucial to ensuring public support for the expansion of the OSW industry and maintaining or improving the welfare of local stakeholders (Kularathna et al. 2019). Based on literature reviews and discussions with industry professionals the co-location options considered in this study are economically and scientifically practical. Our research sought to fill two voids in the Virginia OSW industry by (1) educating the public about potential opportunities within the OSW industry and (2) valuing public preference for practical co-location activities to occupy the ocean space between the turbines of the CVOW farm.

Our research successfully informed a sample of the public about the VA OSW industry, based on the results of the first two questions in the survey. To reiterate, Table 2 shows 62% percent of participants were unaware of the Coastal Virginia Offshore Wind (CVOW) Project before reading the information provided in this survey, while 72% of respondents were unaware of the active Two-Turbine Pilot study prior to reading the information provided in this survey. This level of unawareness suggests room for improvement on information sharing or an education campaign from the energy providers and regulators regarding the expansion of VA's OSW industry.

Estimated willingness-to-pay values were calculated using data collected by a web-based choice experiment. WTP data is helpful information for energy providers, researchers, aquaculturists, and policymakers because it shows the value that the public places on each activity in contrast to the perceived implementation and maintenance costs of each activity. By understanding public predilection through calculating willingness-to-pay, Dominion Energy® and other energy providers can understand how to collaborate with the public on co-location opportunities or circumvent public resistance for implementing certain co-location techniques. Additionally, this level of insight can be valuable to the local and global economy by potentially stimulating healthy competition in research and technological innovation surrounding the possibilities of co-location with the offshore wind industry.

As in any research, there are limitations within this study. As observed in the field research conducted for this paper, occupation is a potential factor in terms of support for the advancement of offshore wind and co-location. In our experience, those working in maritime industries are concerned about how OSW could alter or restrict fishing and shipping routes and recreation areas. It would be interesting to quantify the influence of occupation on WTP values.

Implementation of co-location activities largely depends on the associated costs. It is recommended that regulators and energy providers complete a more comprehensive cost-benefit analysis involving existing feasible co-location technologies, information about permitting processes, and transaction costs associated with the implementation and management of each technique. We also recommend repeating this stated choice, willingness-to-pay approach when new OSW installments are initiated and when information about additional co-location opportunities becomes available.

In sum, the U.S. OSW industry is beginning to grow rapidly and presents exciting opportunities for other businesses to collaborate. While implementation of co-location has logistical and regulatory challenges, our findings demonstrate Virginians associate monetary value with co-location techniques besides public access. In addition to public preference, there are many potential benefits to the local economy and marine environment that favor further exploration of co-location opportunities in the Commonwealth of Virginia.

List of Acronyms

BOEM	Bureau of Ocean Energy Management
CE	Choice Experiment
CL	Conditional Logit
CO_2	Carbon Dioxide
CVOW	Coastal Virginia Offshore Wind
IRB	Institutional Review Board
MW	Megawatt
N	Nitrogen
OSW	Offshore Wind
RUM	Random Utility Model
SQ	Status Quo
U.S.	United States
VA	Virginia
VT	Virginia Tech
WTP	Willingness-to-Pay

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