Evaluating the Economic Feasibility of Fermentation Carbon Capture: A Scenario-Based Sensitivity Analysis of Levelized Cost of Capture in Commercial Wineries

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Introduction

Can carbon capture investments allow wineries to meet their financial and sustainability goals by leveraging government incentives? Wineries are uniquely positioned for carbon capture because the fermentation process produces nearly pure and highly concentrated biogenic carbon dioxide (Co2). Wineries also utilize Co2 in the process of creating wine through blanketing tanks, bottling and sparging. This creates an opportunity within the circular economy to capture the fermentation carbon dioxide through a carbon capture system in order to close the loop and create operational savings.

However, the challenges wineries face are significant as well. The nature of wine making introduces the problem of seasonality. The annual fermentation occurs in the span of six-eight weeks, making the overall usage rate of the carbon capture equipment very low, resulting in a low capacity factor when evaluating as part of a techno-economic analysis, such as through the

Levelized Cost of Capture (LCOC) metric that isolates the technology usage costs of the equipment per ton captured.

Corporations may lack the financial metrics to make informed decisions on purchasing new emerging technology investments such as point source carbon capture technology, the capture system to be evaluated within this research. On the other hand, firms offering carbon capture solutions may lack the information connecting all of the costs and potential benefits associated with adopting their technology. Carbon capture is still considered an emerging technology with little precedent in industries outside of heavy industries (gas, power, concrete, steel, etc.), like viticulture and winemaking. For future reference throughout this research, viticulture may be used to reference the industry of winemaking. Corporate buyers need information to base their purchasing decisions on. The lack of understanding around the costs and benefits of carbon capture technology creates a barrier between corporate adoption of this emerging technology and the potential financial and environmental benefits.

The lack of information surrounding the adoption of carbon capture can discourage firms from investing in technologies that reduce greenhouse gas emissions, a shared world goal from the Paris Climate Initiative. Federal and state governments can incentivize companies to invest in sustainable technologies in order to meet these goals. While these programs exist, applying has strict requirements of verification and tracking. Many companies need to hire external consulting firms to provide support in reporting sustainability metrics, and overall professional navigation of intricate, highly governed and sometimes volatile programs. In the case of the United States federal 45Q program, the largest carbon capture credit program, the minimum capture needed is 12,500 metric tons and requires a Lifecycle Analysis (LCA) to be completed. Overall, navigating the government programs designed to incentivize sustainability is complex and sometimes costly.

While modern companies frequently claim a commitment to the environment, no company exists to serve the environment wholly. The financial metrics used to evaluate the technology as an investment need to align with the company's goals and associated thresholds. Wineries specifically tend to market with environmental stewardship and sustainability initiatives, as the winemaking process is naturally very close to the environment, and the resulting fruits of that environment. Positive consumer sentiment is generally associated with environmental stewardship when it comes to consumables. California alone has multiple sustainability certifications and programs, such as Certified California Sustainable Winegrowing (CCSW) and LODI RULES, alongside United States and worldwide certifications like Low Input Viticulture & Enology (LIVE) Certified Sustainable, SIP (Sustainability in Practice), USDA Certified Organic, etc. Overall, wine companies tend to signal sustainability initiatives to their consumers whenever they can. While carbon capture doesn't directly feed into an official wine label or certification, it can help achieve net zero emissions initiatives.

Carbon capture technology can create operational savings, indirect brand value and revenue, and the potential for performance based tax credits. While there are other potential revenue streams for carbon capture, this research will consider these main benefits.

While prior functional and pilot programs have tested carbon capture technology in viticulture at a small scale, and relatively low cost, carbon capture technology firms, their potential buyers, and the planet would benefit from research that creates a clear picture of the benefits of adopting this technology. In order for carbon capture equipment owners to maximize the benefit through government incentives, the capture volume needs to be significant.

There are a few challenges presented with the production scale of these large commercial wineries. First, they operate as conglomerates with many vineyards, wine production facilities and brands underneath the company name. Adoption of carbon capture technology is generally by facility rather than by company, as the capture process relies on physical proximity of the technology in connection to the fermentation process. One carbon capture membrane can likely service one or a few industrial vats during processing, and all membrane products have their own limitations and maintenance. For research purposes, the experiment will assume the company attempts to capture at least 12,500 metric tons of Co2 in order to qualify for the main United States federal tax credit program, 45Q. The Capital Investment for point source carbon capture membranes will be estimated using Haibo Zhai's plant level baseline framework, previous academic research focused on scaling the costs and systems used to capture, store and utilize carbon.

Carbon capture technology firms will need to meet their target customers with economics in mind. This research paper hypothesizes that large production wineries will be the most likely to break even on investment from carbon capture investments due to the following assumptions.

1) Larger companies are more likely to have the funds and / or access to capital to purchase CCU (Carbon Capture & Utilization) technology.
2) Carbon Capture technologies are a significant capital expenditure that do not directly create new streams of revenue.
3) Gaining federal and state tax incentives require their own time and investment.

Literature Review

"Co2 utilisation [references] the process in which one or more economically valuable products are produced using Co2" (Hepburn et al., 2019). Carbon Capture and Utilization (CCU) will be the chosen intent for the capture for which the technology will be evaluated to the market, as utilization is the ultimate end goal of the carbon product created. Other models exist and have been found to be more lucrative, such as CCS, or Carbon Capture and Sequestration, referring to "the storage of carbon dioxide (CO2) after it is captured from industrial facilities and power plants or removed directly from the atmosphere." (Energy.gov) While this option exists for wineries, it shifts the business model and operations of the company from selling wine to sequestering carbon, or partnering with a company that sequesters the carbon.

Carbon capture as a technology has applications in many industries. The heavy materials industry, such as concrete, iron and steel, are considered "hard to abate", or notoriously difficult to capture carbon. However, "the iron and steel sector ranks first when it comes to CO2 emissions, and second when it comes to energy consumption" (International Energy Agency). So, carbon capture funding and incentives are aligned appropriately within these industries.

Regarding the viticulture industry, carbon capture is much less common, but much easier due to the naturally high purity stream of carbon dioxide created through fermentation. Previous technology pilots have been completed to test carbon capture in the viticulture industry, such as Trefethen Family Vineyard in Napa, California with Earthly Labs' CiCi carbon capture unit and Lawrence Livermore National Lab, estimating that point-source winery capture costs anywhere from $100 to $1,000 per ton of captured Co2, depending on scale. (Lawrence Livermore National Laboratory). Earlier academic pilots pegged the cost of capture around $150/ton, giving us a general baseline for the pricing range of levelized costs.

While pilots are necessary to validate the technology and application in a smaller and controlled environment, scaling the technology is a key consideration for this research hypothesis. In order to create scenarios where carbon capture technology is considered as a standalone capital investment within viticulture, rather than a joint venture or partnership flip, the technology most likely needs to be adopted on a larger scale, relative to the industry. This is because the hurdle to qualify for the main United States government tax credit program, 45Q, requires 12,500 metric tons of carbon to be captured and accurately assessed through a lifecycle analysis (LCA) to be able to qualify for the tax credit. The Life Cycle Assessment is a key assessment tool for determining the environmental impacts of carbon capture and utilization (CCU) systems, especially with respect to decarbonisation of steel manufacturing processes (Suer et al., 2022)

While carbon capture is generally noted as a net positive for the environment, there is research that suggests carbon capture is not always an effective climate solution. For example, "CO2 utilization does not necessarily reduce emissions and does not necessarily deliver a net climate benefit, once indirect and other effects have been accounted for." (Hepburn et al.) This research suggests that while utilization of the products created from carbon capture lower the net costs, the industry, usage, scale and intention for the carbon capture all have an effect on the economic feasibility and climate benefit. The same research also references scaling, "although market penetration can be facilitated by cost competitiveness there is no certainty that the cheapest CO2 utilisation pathways will scale up." (Hepburn et al.) This research provides a baseline of pathways that have been tested and some reasonable doubt for the hypothesis. Fermentation carbon capture through the wine was not tested, and is generally considered an alternative pathway for carbon capture.

According to Girouard & Glasgow of the Wisconsin Law Review, "Congress enacted Section 45Q of the Internal Revenue Code to provide qualifying taxpayers with an income tax credit for each metric ton of carbon oxide that is captured and stored or utilized." Companies aiming to gain the income tax credit as a benefit of adopting carbon capture need to assess the tax code thoroughly, or hire a sustainability consulting firm to do so. The 45Q tax credit program was created in 2008, and was updated in 2018 to encourage more participation (Zaret, 2018) While the current 12,500 ton minimum is a large amount, the government previously had the minimum set at 500,000 tons, barring entry to feasibly participate in emissions reduction for many more companies. The original program from 2008 was amended in 2018 to allow for greater participation through widened definitions (carbon dioxide to carbon oxides, lowered minimum capture thresholds and ability to claim the same year the carbon capture equipment is placed) after missed program goals. Pricing of the carbon dioxide within this program is notable for testing our hypothesis. The pricing differs based on the capture method and the actions after capture. Because we will test carbon capture within an industrial facility for utilization rather than permanent sequestration, the credit is $60.For Federal 45Q, the volume, credit pricing and validation requirements are validated, referencing the Wisconsin Law Review and the Department of Energy:

Utilization or EOR: "For QCO that is captured in an industrial facility and either (i) utilized in an approved manner, or (ii) used as a tertiary injectant in a qualified EOR project and disposed of by the taxpayer, the base credit amount is $12 per metric ton of QCO, and the increased credit amount is $60 per metric ton of QCO.19" (Wisconsin Law Review)

Volume Requirements: A "qualified facility" must capture: (i) in the case of a DAC facility, no less than 1,000 metric tons of carbon dioxide in the applicable tax year (reduced from 100,000 metric tons prior to amendment by IRA);46 (ii) in the case of an electricity generating facility, not less than 18,750 metric tons of carbon oxide in the applicable tax year (reduced from 500,000

metric tons prior to amendment by IRA);47 and (iii) in the case of any other facility, no less than 12,500 metric tons of carbon oxide" (Wisconsin Law Review)

Lifecycle Analysis: To claim the tax credit, taxpayers must successfully demonstrate secure geologic storage of captured carbon or reuse to produce low-carbon products. This occurs through robust and transparent monitoring, reporting, and verification of the stored CO2 processes or lifecycle analysis (LCA) of the reused carbon, overseen by the US Department of the Treasury and the Internal Revenue Service and relies on data collection overseen by the US Environmental Protection Agency and the US Department of Energy. (https://carboncapturecoalition.org/wp-content/uploads/2025/09/45Q-primer-Carbon-Capture-Coalition.pdf)

Carbon capture is possible through a few methods, though we will focus on point source capture through carbon capture membranes. Engineering assumptions for the cost and scalability of carbon capture membrane technology will adopt Haibo Zhai's scaling and cost assumptions from the research paper "Advanced Membranes and Learning Scale Required for Cost-Effective Post-combustion Carbon Capture". This research references Zhai's plant level baseline methodology for cost and scaling assumptions because the research remains the most heavily referenced techno-economic models for carbon capture.

This research discusses what it takes to make carbon capture financially viable, and the learning curve of emerging technologies. Zhai's research informs this paper of "Nth of a Kind" (NOAK) system versus "First of a Kind" system (FOAK), stating that the NOAK systems provide a similar effect of economies of scales for engineering systems. For the purposes of the research, we will assume the technology firm is established enough to provide NOAK systems, better pricing of systems and scalability for large corporations.

The cost of the technology itself is not standardized and relies on many factors, as well as the firm that decides to sell the technology. Zhai states "The overall cost for CO2 capture varies with separation targets, process configuration and design, membrane properties, and installed membrane module price." This research will build on the known inputs of carbon capture technology costs, as well as the known inputs for the viticulture industry and large commercial wine companies, in order to best predict the full CapEx and estimated OpEx.

Regarding OpEx, Zhai's research also finds that operating expenses of these systems is a significant portion (around 70-80%) of the total lifetime cost. Maintenance equipment of carbon capture membranes and electricity are the main components of the OpEx costs, with electricity rates suspected to rise in the future due to wildfires, storms and natural gas exposure (Wiser et al., 2025). While this cost is projected to rise in the near future, other associated costs like beverage grade carbon dioxide are projected to rise as well due to upstream supply chain disruptions. This is a cost that could be avoided if a carbon capture system is implemented, so

this would be a supporting argument to support carbon capture on site rather than relying on an increasingly volatile market.

Method Part

The goal of the exploratory research is to model scaling the costs and potential benefits of carbon capture technology to test its viability in the chosen commercial market. These costs and benefits will be from the perspective of a sample company within the chosen market, California's large volume wine producers. The hypothesis of this research is that within the wine industry, the companies able to scale their capture to the federal 45Q minimum capture requirements are the most likely to benefit, more specifically that these companies would be able to achieve a capture cost of zero after potential benefits are considered.

The scale of the company and their wine operations is important to the hypothesis, as the potential capture amount needs to exceed the federal minimum to apply for the 45Q tax incentive.This research will attempt to mirror data from the few wineries that produce over 50 million gallons of wine, and in turn, over 12,500 metric tons of biogenic carbon dioxide, to test the compatibility of the wine industry to carbon capture technology. The benefits of carbon capture considered are federal government incentives, operational cost savings and potential revenue growth associated with ESG initiatives.

This will be illustrated through elements of a techno-economic analysis (TEA), with the goal to measure the efficiency of the investment. The Levelized Cost of Capture (LCOC) is an estimation of the average lifetime unit cost ($/ton) of capturing CO_2 from an industrial or atmospheric source, inclusive of capital investments, operations, maintenance, energy use and the financing. The LCOC metric will isolate the technology costs of carbon capture within the wine industry before any benefits are introduced, ultimately giving us a figure that estimates the cost per ton captured.

This metric fits the research application and audience because of the assumed early deployment and procurement stage of the technology. The research is assessing the technology fit to a niche market, rather than a specific company. The LCOC shows an estimate of the cost as a point-in-time, rather than a forward looking model. This flexibility is necessary because of the external factors weighed into the metric, such as government credits, electricity rates, and carbon dioxide operational pricing changes. In order for a specific company to evaluate the technology, the model could be highly adapted with company specific data.

From the perspective of a carbon capture technology firm, evaluating the product to the market can be an iterative process, with inputs changing constantly. From the perspective of a company evaluating carbon capture technology, this metric is easily understood and provides an all inclusive financial snapshot. According to Zhai's research, operating costs of the technology are a significant portion of the investment (around 70-80%), so tying the operating costs directly to the CapEx is the most accurate way to estimate the total investment.

Figure 1 : LCOC Calculation

$$\text{LCC} = \frac{\text{PV of Total Lifetime Costs (CAPEX + OPEX)}}{\text{PV of Total Lifetime } CO_2 \text{ Captured}}$$

Figure 2 : Breakdown LCOC in Variables

$$\text{LCOC} = \frac{(\text{TOC} \times \text{CCF}) + \text{FOM} + \text{VOM} + C_{\text{energy}}}{\dot{m}_{\text{CO}_2,\text{annual}}}$$

In order to calculate this metric, we need to accurately assess the CAPEX and OPEX required to scale the carbon capture volume to meet the federal requirements for tax credits. This will be done through referencing formulas from the previously mentioned research on carbon capture membranes to fit the inputs to the industry. The timing input translates the seasonality of the industry into hours to capture the required volume into the CapEx and OpEx costs.

Zhai's plant level baseline formula considers operating and financing expenses, so this formula can be slightly modified to return the Levelized Cost of Capture. Long term operating financing considerations (debt service, interest, return on equity) are captured in a Capital Charge Factor (CCF) within this formula. The Capital Charge Factor (CCF) multiplier embeds the entire present-value discount curve across the facility's lifetime.

The research design will stress test the applicable variables where appropriate to answer the following questions:

1) *How significantly does seasonality impact an industry compared to a non-seasonal one?*
2) *How significantly can operational cost savings affect the LCOC?*
3) *How significantly can 45Q tax credits affect the LCOC?*
4) *How significantly can revenue growth from ESG affect the LCOC?*
5) *Is there a point where captured volume causes the LCOC metric from any of the scenarios (Figure 3) to be zero or negative?*

The following scenarios (Figure 3) introduce the scenarios used to stress test the volume of capture under certain conditions. Scenario 1 will produce the traditionally calculated LCOC from the established variables (Figure 4 and 5) in the viticulture industry, but will adjust the timing to accommodate 50 weeks in a year to capture the set volume of carbon rather than the 8 weeks that is common for winemaking. Scenario 2 will produce the traditionally calculated LCOC with seasonality, or 8 weeks to capture. The only variable changed in this scenario is the time to capture. Scenario 2a will show the outcome of the LCOC from Scenario 2 (viticulture LCOC) considering the addition of operational cost savings, or variable C1. This scenario estimates a limit to this benefit of 500 tons of carbon dioxide, as not all Co2 created can realistically be utilized by the company operations alone. This benefit considers that winemaking can require carbon dioxide to aid the process of creating wine, as an input or as an addition to the final product, as validated by a sustainability professional within a sample market company. Scenario 2b considers the addition of 45Q tax credits into the viticulture LCOC, where the benefit of $60 per ton captured can expand without limit, theoretically. In reality, a winery is limited in the production of wine, and thus carbon dioxide, due to natural resources and capacity. This benefit recognizes and includes the associated cost of $75,000 for the completion of a Lifecycle Analysis that is required to validate capture and tracking.

Figure 3: Levelized Cost of Capture Scenario Details

Metric Case	Description
1. Base Metric - No Seasonality LCOC	LCOC Metric (Figure 1) with time input equal to 50 weeks (no seasonality)
2. Base Metric - Viticulture LCOC	LCOC Metric (Figure 1) with time input equal to 8 weeks (viticulture seasonality)
2a. Operational Cost Savings (C1)	Factors in the cost savings of circular high purity Co2 usage, with the assumption that wineries can recycle usage up to 500 tons at a cost savings of a conservative estimate of $200 per ton (source: Airgas)
2b. 45Q Tax Credits (C2)	Factors in the benefit of the federal 45Q Carbon Credit at a price of $60/ metric ton and the additional cost of a Lifecycle Analysis (LCA) at a cost of $75,000.

2c. ESG Related Revenue Growth (C3)	Factors in the potential indirect revenue created by positive ESG claims (Net Zero, Sustainable Marketing, etc.) at .05% of the sample company's base revenue, or $75,000
2e. Net LCOC	Incorporates all benefits (C1, C2, C3) into a Net LCOC for the viticulture industry

The scenario based LCOC metrics can be interpreted as the cost per ton of carbon captured, under the respective scenario. Many companies in the United States would interpret an LCOC of less than $60 to be a net gain, since carbon is commonly valued at $60 due to the federal 45Q credit program, for capture and utilization (CCU).

To summarize, the research follows a series of high level choices in the market, illustrated through Figure 4. Attempting an emerging technology in a new market is ambitious and needs to be heavily validated through techno-economic metrics like the LCOC. This metric is supported by research from the literature review, data validated through industry professionals and assumptions that follow the market factors in Figure 4. At a high level, the LCOC metric will illustrate the compatibility of the technology with the chosen market. However, there are other considerations that contribute to the final metric.

Figure 4 : Carbon Capture Market Factors

Factor	Detail	Reason	Known Alternatives
1. Technology	Carbon Capture Membranes	Flexible and small, good for multiple fermentation facilities	Embedded plant systems, designed and built into the industrial plant
2. Capture Type	Point Source	Point source captures from a source (fermentation), rather than the alternative gathering and purifying from open air	Direct Air Capture
3. Market	Large, Commercial Wineries	Wine fermentation naturally produces high purity carbon dioxide, and winemaking consumes carbon dioxide in multiple ways. Large wine companies are more likely to benefit from carbon capture as the	Concrete, gas, steel, etc.

		research hypothesis.	
4. Credit Model	Carbon Capture & Utilization (CCU)	Carbon dioxide is utilized in winemaking, and typically bought and delivered through suppliers like Airgas	Carbon Capture & Sequestration (CCS), typically requires a partner organization to pursue
5. Scale of Capture System	Minimum 12,500 tons	In order to apply for government tax credit program, 45Q	Flexible capture amounts based on industry production and capture intent

The variables derived from the technology setup will be estimated based on Zhai's plant level design baseline, where the number of membranes required to capture a certain volume of carbon dioxide can be estimated through financial, operational and engineering inputs. The volume of carbon captured is assumed to pass through the membrane at its capacity. However, to accommodate viticulture's seasonality, a time constraint will be introduced to customize the count of membranes and the associated increased CapEx of the project. Essentially, the seasonality of the industry intensifies the CapEx requirements by a factor of the operating time to the year, so about four times the amount of CapEx is needed to accommodate the wine industry.

To collect the relevant data, I focused on finding all inputs mentioned in Zhai's formula to estimate CapEx and OpEx. A full list of variables for this formula can be found in Appendix 1. The operational equipment variables were validated by an emerging carbon capture technology company, Spear the Air, Inc from Boston, Massachusetts. Operational usage assumptions were validated by a sustainability engineer working with one of the large California wineries, assumed to be the end consumer within the target market.

Financial assumptions taken about government carbon capture credits, more specifically the cost assumption of an Lifecycle Analysis (LCA) as a requirement to accompany a 45Q application, were validated with a sustainability consultant from a third party sustainability firm. These firms work with public and private companies to maintain sustainability compliance. Financial assumptions taken from company specific data are taken from one of the main companies within our target market, specifically the WACC and revenue assumption used to estimate financing and revenue growth associated with ESG effects. Publicly available company data and academic research was referenced to inform the calculations to mirror real world cost scenarios, taking assumptions when necessary to build our scenarios.

Scenario Assumptions & Limitations

This model is a general estimate of LCOC under the circumstances mentioned in Figure 4.There are some limitations and assumptions taken with this model in order to create and stress test the scenarios.To test our hypothesis that large wine companies would benefit from carbon capture technologies, the following assumptions are made when designing the research and gathering the data:

1. All carbon captured is within the Bay Area, California (Napa).
2. All carbon captured has an operational cost savings or value.

These assumptions are made to bridge certain gaps within the research method, such as the criteria to apply for Federal 45Q. In this tax legislation program, the capture method and the end result of the carbon matters to the credit value. One limit within the research method is the potential that wine companies may be able to capture a certain level of carbon, but may not be able to operationally use all the carbon dioxide. In this way, the wine company itself matters, as some may have more uses for Co2 based on their end products. To address this, the assumption is taken that all carbon captured has a value under Federal 45Q, but the operational savings benefit variable maximizes at a threshold of 500 tons.

The following variables show the inputs used to produce outcomes from the research model. A full list of variables are available in Appendix 1.

Figure 5: Physical / Engineering Inputs

	Variable	**Definition**	**Model Value(s)**	**Source**
1	Plant Lifetime	Economic Lifetime	20 years	Standard Assumption
2	Membrane Lifetime Years	Lifetime of membranes before full replacement	5 years	Standard assumption for carbon capture membranes
3	Operating Time	The amount of time in hours set to capture the level of carbon dioxide volume level specified	Seasonal: 1344 hours Non-Seasonal: 7000 hours	8 weeks estimated for wine fermentation season; 50 weeks estimated for a non seasonal industry
4	Annual Capture Volume	The level of capture volume required that will determine the requirements of the carbon capture system	12,500 tons	Required by US Federal 45Q program

Figure 6: Financial Inputs

	Variable	**Definition**	**Model Value(s)**	**Source**
1	WACC	Weighted Average Cost of Capital is used to calculate Net Present Value & any other metrics utilizing a discount rate. Inputs: Cost of Equity (8.08%), Cost of Debt (9.1%), Weight of Debt (33.28%)	8.42%	Estimated from reviewing sample company's Cost of Equity, Risk Free Rate + Beta and Cost of Debt
2	Electricity Rate	Estimated as the per metric ton cost of electricity, reported by PG&E B-19 or B-20 Industrial rates	$55 per metric ton of carbon capture	Pacific Gas & Electric website (regional public utility for Bay Area, California)
3	Operating Labor Cost	Labor associated with operating carbon capture equipment	$2,000 allocated per membrane	Conservative estimate of localized Bay Area labor required for maintenance per membrane

Results Analysis

The below table shows the outcome of each scenario calculated with the established variables using Zhai's plant level baseline for estimating CapEx and OpEx for a carbon capture membrane system.

Figure 7: LCOC Scenario Outcomes

Metric Case	Output
1. Non Seasonal	$78.86
2. Base Viticulture	$184.92
2a. Operational Cost Savings (C1)	$104.92
2b. 45Q Tax Credits (C2)	$130.92
2c. ESG Related Revenue Growth (C3)	$178.92
2d. Net LCOC (inclusive of all benefits)	$44.92

The research results produce three sets of sensitivity analyses, with full results found in Appendix 2, 3, 4.

The Net LCOC metric is the most useful to show the effects of the benefits of carbon capture. The results from this metric all being over zero proves that at least one of the conditions of our experimental research is incompatible with each other. Carbon capture is utilized in other heavy industry markets, but is emerging in smaller alternative markets outside of heavy industries. Our high level choice of evaluating the technology to the wine industry is generally incompatible. The Net LCOC takes into consideration the potential benefits of the carbon capture system to offset the cost, but fails to hit zero or below in these scenarios, indicating there is no payback for the equipment.

The findings of Scenario 1 versus Scenario 2 show that the seasonality of the industry chosen has a massive impact on the LCOC metric. As previously stated, the lack of time associated with seasonality intensifies the CapEx requirement about four times over, as the non seasonal metric allows for 7,000 hours annually to capture the same amount of Co2. The lack of time acts as a bottleneck in the engineering process, where the membranes required for capturing 12,500 tons of Co2 increase from 28 to 145. The constraint increases the cost of the initial capital, but also increases the associated operating expenses, established within the foundational research to be around 70-80% of the total lifetime costs.

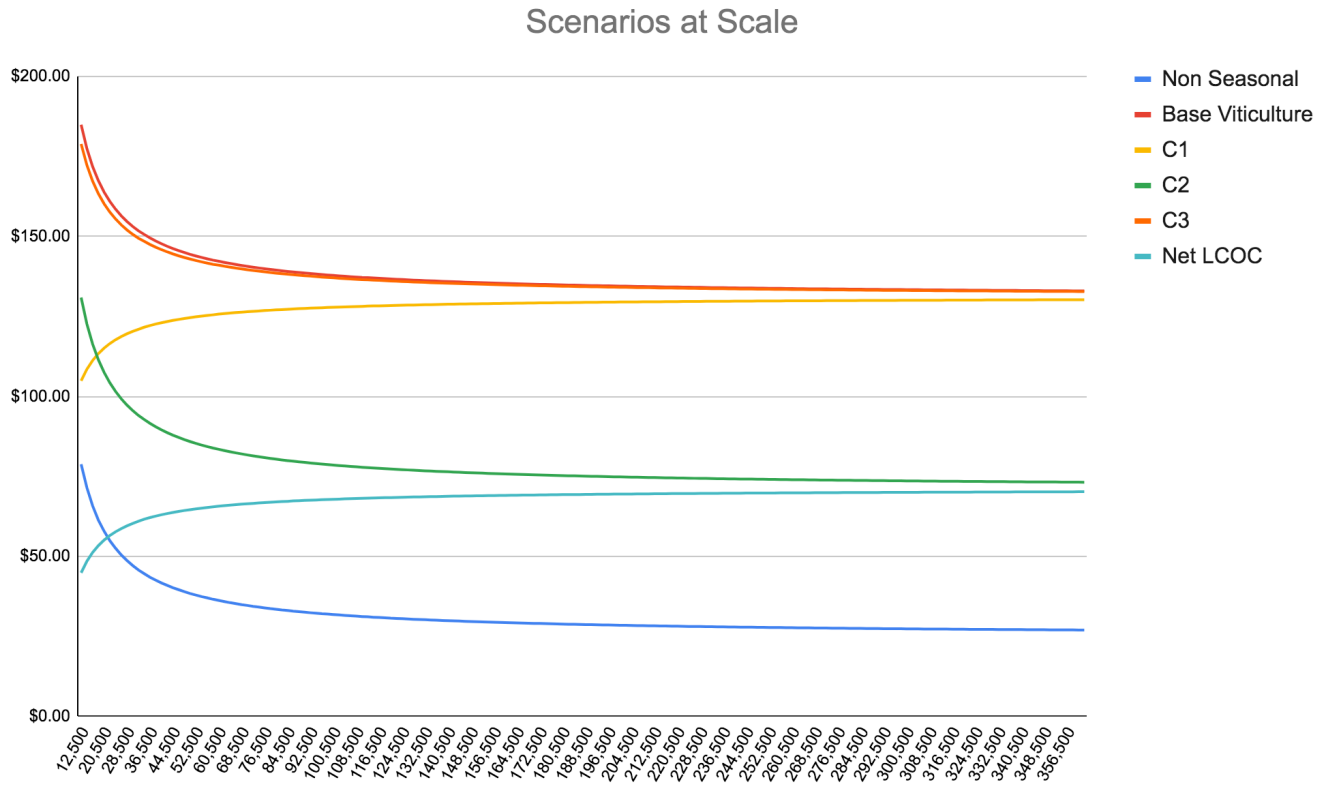


Figure 8: Scenarios at Scale

The scaled results (Figure 8, Appendix 5) also show that there is no scenario where the LCOC can reach zero or negative. This indicates that the cost to capture will always be a net expense to wineries, even if the potential benefits are included in the metric. To answer the other questions associated with our hypothesis, the LCOC scenarios are scaled from the 45Q capture minimum of 12,500 to 356,500 for all scenarios (Figure 8). This sensitivity analysis shows a diminishing return effect for the Base Metric, C3 Benefit, C2 Benefit and Non - Seasonal Metric around 36,000 tons captured. For the C1 Benefit and Net LCOC Metric, the effect is the inverse, increasing until approximately 36,000 tons captured.

The scenarios at scale visual (Figure 8) shows that the best result comes from the viticulture industry, without seasonality. In this scenario, the time variable allows for 50 weeks of capture versus the seasonal 8 weeks that the wine industry is known for. This metric follows the same general curve, where the LCOC cost flattens around 60,000 tons captured, with the capture volume effect on LCOC continuing to diminish.

The next best scenario is the Net LCOC metric, with the lowest cost to capture at the lowest volume, the starting minimum volume of 12,500 tons. The beneficial effects of capture diminish after 12,500 tons captured and the LCOC flattens at around $70.00 and 285,000 metric

tons captured. In this scenario, there is a curve upward and no incentive to continue capture after 12,500 metric tons.

The individual benefit scenarios (C1, C2, C3) in Figure 8 show how these benefits scale. The federal 45Q benefit (C2) scales with the volume of capture, but fails to offset the cost of capture by a level that would incentivize carbon capture systems. The benefit flattens the LCOC to approximately $80.00 around 84,500 tons captured. The benefit scenario C1, or organizational cost savings, does not improve with scale. This makes sense with the context that wineries may not buy more than a certain level of Co2 for their operations, so replacing the volume cost of Co2 from a supplier does not scale. The benefit scenario C3, or ESG Revenue Growth, does not scale either, as the assumption made was environmental stewardship, and the associated marketing effect, can increase revenue growth, but is not tied to the scale of the volume captured. The effect maximizes at .05% of the sample company's revenue growth, or $75,000.

The research is designed to scale capture to a level of volume that considers the federal 45Q program minimum. This consideration informed the original hypothesis, that wine companies able to scale to this level were the most likely to benefit. Unfortunately, the credit amount of $60 for carbon capture and utilization is not enough to incentivize this market to invest in carbon capture technology, at this level.

The research is also indirectly testing the ability for companies to independently capture carbon, without the dependence of financial or organizational partnership to invest in the technology, or sell the Co2 at other credit amounts, respectively. Overall, navigating government programs in order to fund large corporate investments can be a challenge in practice.

Managerial Recommendations

The analysis of the research scenarios and associated questions finds that the estimated cost of carbon capture outweighs the benefits, so the cost to capture will always be a net expense for wineries. In general, the seasonality of the wine industry pushes the research model metric to a level that corporations would generally find unappealing to pursue. Because this research sits at the intersection of selling carbon capture technology, and buying carbon capture technology, the recommendations will consider the two different perspectives. The buyer in this case would most likely be a sustainability manager. The seller in this case would be a carbon capture firm.

From the perspective of a sustainability manager, I would not completely discard the capabilities of carbon capture, but I would not pursue a sole investment of carbon capture at this level. The next potential option I would consider is a leasing model of the carbon capture equipment at an individual plant level. This option would overlook the government credit program route, and focus on the operational savings and ESG revenue growth, while removing the challenge of seasonality. The federal 45Q program would be incompatible here, as one of the criteria for applying is ownership of the carbon capture equipment.

The next option I would consider would be adoption of capture through one facility, and a smaller goal of capture. This would allow one facility to create Co2 that could potentially be distributed to other facilities on a local scale. This method may culminate in a higher cost of capture, but would still support ESG goals and innovation. This gives the winery the option to explore operational uses of carbon capture at a smaller, pilot level.

From the perspective of the seller evaluating the technology fit to different markets, I would continue market research to evaluate the potential of a lower LCOC by selling in markets outside of the United States, specifically in Europe. Countries in Europe likely have more aggressive incentives for decarbonization, which would result in lower costs of capture.

My last recommendation would be to look for organizations that may be willing to partner to pursue carbon sequestration, or a CCS business model over a CCU business model. Carbon sequestration is a lengthier process that relies on other parties, transport and a geologic sequestration process, but the incentives are greater under the federal 45Q program, at $85 per ton over the $60 per ton that was used in this research (Jones & Marples, 2023). Ideally, this partner company would own the capture equipment, run the equipment during the short fermentation cycle of eight weeks to capture the carbon, sequester the carbon and validate through the Lifecycle Analysis process. While the owner of the capture equipment is the party that is able to apply for 45Q, that company would likely compensate the wine company for a

certain percentage for providing the site and fermentation point source. This would allow the winery to remain within the same business model without taking on the investment risk of a full capture system.

Conclusion

Within the chosen research method and associated metric, there are limits. Using estimations informed by real world data help to minimize these limits, but ultimately defining a specific company would provide the most accurate metrics for LCOCs. The estimation of the scaled technology relies on foundational research on capture systems by Haibo Zhai, but a real world company offering carbon capture systems would better inform the result of the CapEx. Overall, the research provides a high level estimate of carbon capture investment outcomes, but doesn't find the best economic fit within the wine industry.

The results of the industry to the technology were not entirely surprising, as carbon capture is used more in energy, oil and heavy materials. This research is meant to connect carbon capture technologies and their financial feasibility in our chosen market, following the techno-economic process as a baseline, aligning costs, incentives and equipment, with point source carbon capture as the equipment and commercial wineries as the industry. After evaluating membrane-based carbon capture technology to the wine industry, we find that, even when attempting to scale the usage, the industry is still incompatible with estimations of the scaled technology. Outside of the incompatibility of the technology to the industry, there are several contributing factors: government incentive climate, and organizational independence.

Under federal United States government programs designed to incentivize carbon capture, the credit value generally does not push smaller capture industries, or those outside of the heavy industries, to prioritize carbon capture for decarbonization goals. California's state government incentives were generally incompatible with the research. So, the carbon capture climate may be more favorable in other countries and should be evaluated.

The research was also indirectly testing the ability for a large company to pursue the carbon capture investment independently. The outcome of the research generally shows that this is discouraged. Even the partnership of a consulting firm that specializes in obtaining carbon credits would be heavily encouraged when pursuing this venture. A financing or sequestration partner would also offer the opportunities to maximize the carbon capture investment. While this research did not offer encouraging results for sole companies to invest in carbon capture and utilization, the potential to maximize carbon capture would likely need the expertise of at least two organizations.

Self Assessment

In the process of writing this dissertation and completing the associated internship, I learned about product engineering, carbon market and government incentives associated with carbon capture systems. I also learned to construct my ideas with many factors at play, and attempted to connect engineering costs and limitations to the larger market.

I attempted to collaborate with many individuals in order to explore the topic more. I was able to validate engineering inputs with Spear the Air, sustainability consulting assumptions with a sustainability consultant, and sustainability considerations with an industry professional in the chosen market. I believe I could have collaborated more, but spent most of my time testing new research methods.

My idea for this master's dissertation evolved from the need to create a pricing strategy for my internship company, a startup called Spear the Air, Inc. which is an early stage carbon capture technology company. The company was very new, and centered around point source carbon capture technology developed by a few engineering colleagues. While I have worked for a startup in the past, this was a new experience for me. The company structure needed to be built around the technology; I separated the idea that a product and a company are one and the same. One research and strategy assignment I had was to create the pricing for the product. From a corporate finance perspective, this is not a simple task. The market for the technology is still emerging, and the solutions that exist did not have transparent pricing. Part of the consideration in the pricing strategy was to pursue a leasing or purchase model. I had to defend the idea that large companies would likely be the purchaser of this technology, and wineries were the current target market chosen by the company leadership.

My idea evolved from creating a type of project finance model that connected the benefits of government incentives, and potential financial benefits, to utilizing the Levelized Cost of Capture (LCOC) and translating these requirements into a project finance model, to pursuing only the Levelized Cost of Capture scenarios. This was because I felt that evaluating a generic capture system to a generic company with estimates of an industry allowed for too many variables and unknowns. The research method I used could be argued to have too many unknowns. Ultimately, I believe the method I used fit the stage of the company's technology well, as Spear the Air is actively validating the technology fit to different markets. In my research, I found that the techno-economic analysis (TEA) is usually completed by a third party. In reality, I felt that adopting the same metrics made the most sense.

In my internship, I heavily researched the industry, the associated government incentives and the carbon market. I validated many assumptions that were unclear, and even found corrections on the values very late in the process. Personally, I think I could have improved by trying new methods and eliminating ideas sooner because many of the pivots in my analysis and validations happened in the last month before the due date, putting pressure on the timeline.

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Appendix 1: Zhai's Plant Level Baseline for Calculating Carbon Capture CapEx

Variable Name	Typical Units	Description	Role in the Model
Target Volume	m3 (STP)	Total volume of CO2 gas to capture over operating window	Input (Sizing): Sizing basis for required instantaneous gas throughput
Operating Time	hours	Time window allocated to process Target_Volume (typically 8760 h)	Input (Operational): Timing baseline to convert target volume into continuous flow rate
Capacity Factor	fraction (0−1)	Annual plant availability factor accounting for planned/unplanned downtime	Input (Operational): De-rates annual hours to calculate active operating throughput
CO2 Molar Vol	m3/kmol	Standard molar volume of ideal gas at STP (0◦C,1 atm=22.414)	Physical Constant: Converts volumetric flow rate into molar flow rate
Permeance GPU	GPU	Pressure-normalized CO2 transport rate across the selective layer	Input (Membrane): Primary material performance metric; scales required surface area
P Feed	bar	Total absolute pressure of the flue gas entering the membrane feed side	Input (Process): Establishes upstream partial pressure driving force
Y Feed	fraction (0−1)	Mole fraction of CO2 in the raw feed gas stream	Input (Process): Sets feed-side CO2 concentration and overall gas volume
P Perm	bar	Absolute vacuum suction pressure maintained on the permeate side	Input (Process): Establishes downstream partial pressure driving force
Y Perm	fraction (0−1)	Mole fraction of CO2 in the enriched permeate stream	Input (Process): Sets permeate-side CO2 concentration and driving force
Area per Module	m2/module	Active surface area contained in a	Input (Equipment):

		standard commercial module housing	Divisor used to convert total system area into module count
Total Molar Capture Rate	kmol/s	Continuous instantaneous molar capture rate while the plant is operating	Intermediate (Mass Transport): Baseline molar flow for sizing area and machinery
Delta P CO2 (Log-Mean or Representative Co2 Driving Force)	bar	Net transmembrane partial pressure driving force ($p_{f,CO2} - p_{p,CO2}$)	Intermediate (Mass Transport): Pressure gradient driving molecular permeation
Flux CO2	kmol/(m2·s)	Net molar transfer rate of CO2 per unit of active membrane area	Intermediate (Mass Transport): Normalized flux rate dividing total required throughput
Total Area	m2	Total active membrane surface area required across the capture stage	Intermediate (Sizing): Direct sizing output determining bare module CAPEX & VOM
N Modules	count	Discrete number of commercial membrane module elements to install	Output (Hardware): Physical cartridge and vessel procurement count
Unit Membrane Price	$/m2	Turnkey capital purchase price per unit area for new membrane elements	Input (Cost): Primary pricing unit for bare uninstalled membrane capital
BoP Factor	fraction (0−1)	Balance of Plant markup for skid frames, housings, manifolds, and piping	Input (Cost): Multiplier scaling bare membrane area into full skid equipment
Cost Rotating Equip	$	Direct purchased capital cost for blowers, vacuum pumps, and compressors	Input / Formula (Cost): Sized capital cost for mechanical gas-handling assets
Eng Fee Pct	fraction (0−1)	Engineering, Procurement, and Construction Management (EPCM) fee	Input (Financial): Standard overhead factor applied to direct facilities capital
Process Contingency	fraction (0−1)	Contingency budget covering technology maturity and performance risk	Input (Financial): Risk buffer applied to direct facilities capital

Project Contingency	fraction (0−1)	Contingency budget covering unforeseen site and construction cost variances	Input (Financial): Scope contingency factor applied to direct facilities capital
Owner Costs Pct	fraction (0−1)	Pre-production startup costs, land, permitting, and owner project management	Input (Financial): Soft cost factor converting TPC into Total Overnight Capital (TOC)
PFC	$	Process Facilities Capital (membrane skids + rotating equipment)	Intermediate (CAPEX): Direct bare-erected equipment and installation capital base
TPC	$	Total Plant Cost (PFC+Engineering+Contingencies)	Intermediate (CAPEX): Direct and indirect construction cost baseline
Total Overnight Capital	$	Final overnight capital cost (TPC+Owner’s Costs)	Output (CAPEX): Total upfront project capital expenditure to be amortized
CCF	percentage	Capital Charge Factor / Fixed Charge Rate annualizing upfront capital	Input / Formula (Financial): Multiplier blending WACC and lifetime to convert TOC to $/yr
Plant Life Years	years	Economic and operational lifetime of the capture facility	Input (Financial): Amortization and recovery window for plant financing
Membrane Life Years	years	Useful operating service life of membrane cartridges before degradation	Input (Operational): Replacement period divisor defining annual module restock cycle
Unit Replace Price	$/m2	Bare cartridge element replacement cost (excluding permanent housings/skids)	Input (Cost): Unit price used to calculate recurring periodic module replacement
Electricity Price	$/kWh	Industrial delivered electricity tariff	Input (Economic): Rate converting parasitic kilowatt-hour draw into operating expense

Total Power kW	kW	Total electric auxiliary load of blowers, vacuum pumps, and compressors	Intermediate (Energy): Combined active electrical demand driving plant parasitic power
Labor Cost Annual	$/year	Annual base salaries and burdens for dedicated operating and maintenance staff	Input (Cost): Base fixed operational labor budget
Annual Captured Tonnes	tons/yr	Total mass of pure CO2 captured and delivered over a full calendar year	Output (Throughput): Denominator dividing annualized cash flows to produce LCOC
Annual Capital Charge	$/year	Annual capital recovery expense (TOC×CCF)	Intermediate (LCOC): Amortized annual debt service, equity return, and taxes
Annual FOM	$/year	Annual Fixed Operation & Maintenance (labor, routine maintenance, admin)	Intermediate (LCOC): Fixed operational cash outflow independent of hourly runtime
Annual VOM	$/year	Annual Variable Operation & Maintenance (membrane cartridge replacement)	Intermediate (LCOC): Variable operational cash outflow for consumables replacement
Annual Energy Cost	$/year	Annual utility electricity expense for all gas-handling machinery	Intermediate (LCOC): Variable energy cash outflow to power blowers, vacs, compressors
Gross LCOC	$/ton CO2	Gross Levelized Cost of Capture ((Capital+OPEX)/Tonnes)	Output (Benchmark): True engineering cost to capture one metric tonne of CO2
Power Blower	kW	Electric power consumed by the flue gas booster blower	Intermediate (Energy): Machine-level power demand overcoming stage feed pressure drops
Power Vac Pump	kW	Electric power consumed by the permeate vacuum pump	Intermediate (Energy): Machine-level power demand pulling suction on the membrane permeate

Power Compressor	kW	Electric power consumed by the multi-stage pipeline compressor train	Intermediate (Energy): Machine-level power demand boosting captured CO2 to pipeline pressure
WACC	percentage	Weighted Average Cost of Capital / blended hurdle rate for debt and equity	Input (Financial): Discount rate reflecting project financing risk and return targets

Appendix 2: Sensitivity Analysis of WACC / Capture Volume on LCOC - Non Seasonal										
Capture Volume	WACC									
$ 78.86	7.00%	7.50%	8.00%	8.42%	8.50%	9.00%	9.50%	10.00%	10.50%	11.00%
12,500	$ 77.54	$ 77.99	$ 78.46	$ 78.86	$ 78.93	$ 79.41	$ 79.90	$ 80.39	$ 80.89	$ 81.40
13,000	$ 75.45	$ 75.91	$ 76.37	$ 76.77	$ 76.85	$ 77.33	$ 77.81	$ 78.31	$ 78.80	$ 79.31
13,500	$ 73.52	$ 73.98	$ 74.44	$ 74.84	$ 74.92	$ 75.40	$ 75.88	$ 76.37	$ 76.87	$ 77.38
14,000	$ 71.91	$ 72.36	$ 72.83	$ 73.23	$ 73.30	$ 73.78	$ 74.27	$ 74.76	$ 75.26	$ 75.77
14,500	$ 70.23	$ 70.69	$ 71.15	$ 71.55	$ 71.63	$ 72.11	$ 72.59	$ 73.09	$ 73.58	$ 74.09
15,000	$ 68.67	$ 69.12	$ 69.59	$ 69.99	$ 70.06	$ 70.54	$ 71.03	$ 71.52	$ 72.02	$ 72.53
15,500	$ 67.20	$ 67.66	$ 68.13	$ 68.52	$ 68.60	$ 69.08	$ 69.57	$ 70.06	$ 70.56	$ 71.06
16,000	$ 65.83	$ 66.29	$ 66.76	$ 67.15	$ 67.23	$ 67.71	$ 68.20	$ 68.69	$ 69.19	$ 69.69
16,500	$ 64.54	$ 65.00	$ 65.47	$ 65.86	$ 65.94	$ 66.42	$ 66.91	$ 67.40	$ 67.90	$ 68.40
17,000	$ 63.33	$ 63.79	$ 64.26	$ 64.65	$ 64.73	$ 65.21	$ 65.69	$ 66.19	$ 66.69	$ 67.19

17,500	$ 62.19	$ 62.65	$ 63.11	$ 63.51	$ 63.59	$ 64.07	$ 64.55	$ 65.04	$ 65.54	$ 66.05
18,000	$ 61.11	$ 61.57	$ 62.03	$ 62.43	$ 62.51	$ 62.99	$ 63.47	$ 63.96	$ 64.46	$ 64.97
18,500	$ 60.09	$ 60.55	$ 61.01	$ 61.41	$ 61.48	$ 61.96	$ 62.45	$ 62.94	$ 63.44	$ 63.95
19,000	$ 59.25	$ 59.71	$ 60.18	$ 60.57	$ 60.65	$ 61.13	$ 61.61	$ 62.11	$ 62.61	$ 63.11
19,500	$ 58.33	$ 58.79	$ 59.25	$ 59.65	$ 59.73	$ 60.21	$ 60.69	$ 61.19	$ 61.69	$ 62.19
20,000	$ 57.46	$ 57.91	$ 58.38	$ 58.78	$ 58.85	$ 59.33	$ 59.82	$ 60.31	$ 60.81	$ 61.32
20,500	$ 56.62	$ 57.08	$ 57.55	$ 57.94	$ 58.02	$ 58.50	$ 58.99	$ 59.48	$ 59.98	$ 60.48
21,000	$ 55.83	$ 56.29	$ 56.75	$ 57.15	$ 57.23	$ 57.71	$ 58.19	$ 58.69	$ 59.19	$ 59.69
21,500	$ 55.07	$ 55.53	$ 56.00	$ 56.39	$ 56.47	$ 56.95	$ 57.44	$ 57.93	$ 58.43	$ 58.93
22,000	$ 54.35	$ 54.81	$ 55.28	$ 55.67	$ 55.75	$ 56.23	$ 56.72	$ 57.21	$ 57.71	$ 58.21
22,500	$ 53.66	$ 54.12	$ 54.59	$ 54.98	$ 55.06	$ 55.54	$ 56.03	$ 56.52	$ 57.02	$ 57.52
23,000	$ 53.00	$ 53.46	$ 53.93	$ 54.32	$ 54.40	$ 54.88	$ 55.37	$ 55.86	$ 56.36	$ 56.86
23,500	$ 52.48	$ 52.94	$ 53.40	$ 53.80	$ 53.88	$ 54.35	$ 54.84	$ 55.33	$ 55.83	$ 56.34

24,000	$ 51.87	$ 52.33	$ 52.79	$ 53.19	$ 53.27	$ 53.75	$ 54.23	$ 54.73	$ 55.23	$ 55.73
24,500	$ 51.29	$ 51.75	$ 52.21	$ 52.61	$ 52.69	$ 53.16	$ 53.65	$ 54.14	$ 54.64	$ 55.15
25,000	$ 50.73	$ 51.19	$ 51.65	$ 52.05	$ 52.13	$ 52.61	$ 53.09	$ 53.59	$ 54.08	$ 54.59
25,500	$ 50.19	$ 50.65	$ 51.12	$ 51.51	$ 51.59	$ 52.07	$ 52.55	$ 53.05	$ 53.55	$ 54.05
26,000	$ 49.68	$ 50.13	$ 50.60	$ 51.00	$ 51.07	$ 51.55	$ 52.04	$ 52.53	$ 53.03	$ 53.54
26,500	$ 49.18	$ 49.64	$ 50.10	$ 50.50	$ 50.57	$ 51.05	$ 51.54	$ 52.03	$ 52.53	$ 53.04
27,000	$ 48.70	$ 49.16	$ 49.62	$ 50.02	$ 50.10	$ 50.58	$ 51.06	$ 51.55	$ 52.05	$ 52.56
27,500	$ 48.24	$ 48.70	$ 49.16	$ 49.56	$ 49.63	$ 50.11	$ 50.60	$ 51.09	$ 51.59	$ 52.10
28,000	$ 47.88	$ 48.34	$ 48.81	$ 49.20	$ 49.28	$ 49.76	$ 50.24	$ 50.74	$ 51.24	$ 51.74
28,500	$ 47.45	$ 47.91	$ 48.38	$ 48.77	$ 48.85	$ 49.33	$ 49.81	$ 50.31	$ 50.81	$ 51.31
29,000	$ 47.04	$ 47.49	$ 47.96	$ 48.36	$ 48.43	$ 48.91	$ 49.40	$ 49.89	$ 50.39	$ 50.90
29,500	$ 46.63	$ 47.09	$ 47.56	$ 47.95	$ 48.03	$ 48.51	$ 49.00	$ 49.49	$ 49.99	$ 50.49
30,000	$ 46.25	$ 46.70	$ 47.17	$ 47.57	$ 47.64	$ 48.12	$ 48.61	$ 49.10	$ 49.60	$ 50.11

30,500	$ 45.87	$ 46.33	$ 46.79	$ 47.19	$ 47.27	$ 47.75	$ 48.23	$ 48.72	$ 49.22	$ 49.73
31,000	$ 45.51	$ 45.96	$ 46.43	$ 46.83	$ 46.90	$ 47.38	$ 47.87	$ 48.36	$ 48.86	$ 49.37
31,500	$ 45.15	$ 45.61	$ 46.08	$ 46.47	$ 46.55	$ 47.03	$ 47.52	$ 48.01	$ 48.51	$ 49.01
32,000	$ 44.81	$ 45.27	$ 45.74	$ 46.13	$ 46.21	$ 46.69	$ 47.18	$ 47.67	$ 48.17	$ 48.67
32,500	$ 44.48	$ 44.94	$ 45.41	$ 45.80	$ 45.88	$ 46.36	$ 46.84	$ 47.34	$ 47.84	$ 48.34
33,000	$ 44.24	$ 44.70	$ 45.16	$ 45.56	$ 45.63	$ 46.11	$ 46.60	$ 47.09	$ 47.59	$ 48.10
33,500	$ 43.93	$ 44.38	$ 44.85	$ 45.25	$ 45.32	$ 45.80	$ 46.29	$ 46.78	$ 47.28	$ 47.79
34,000	$ 43.62	$ 44.08	$ 44.55	$ 44.94	$ 45.02	$ 45.50	$ 45.98	$ 46.48	$ 46.98	$ 47.48
34,500	$ 43.33	$ 43.79	$ 44.25	$ 44.65	$ 44.72	$ 45.20	$ 45.69	$ 46.18	$ 46.68	$ 47.19
35,000	$ 43.04	$ 43.50	$ 43.97	$ 44.36	$ 44.44	$ 44.92	$ 45.40	$ 45.90	$ 46.40	$ 46.90
35,500	$ 42.76	$ 43.22	$ 43.69	$ 44.08	$ 44.16	$ 44.64	$ 45.13	$ 45.62	$ 46.12	$ 46.62
36,000	$ 42.49	$ 42.95	$ 43.42	$ 43.81	$ 43.89	$ 44.37	$ 44.86	$ 45.35	$ 45.85	$ 46.35
36,500	$ 42.23	$ 42.69	$ 43.16	$ 43.55	$ 43.63	$ 44.11	$ 44.59	$ 45.09	$ 45.59	$ 46.09

37,000	$ 41.98	$ 42.43	$ 42.90	$ 43.30	$ 43.37	$ 43.85	$ 44.34	$ 44.83	$ 45.33	$ 45.84

Appendix 3: Sensitivity Analysis of WACC / Capture Volume on LCOC in Viticulture

Capture Volume	WACC									
184.92	7.0%	7.5%	8.0%	8.42%	8.5%	9.0%	9.5%	10.0%	10.5%	11.0%
12,500	$ 178.05	$ 180.43	$ 182.86	$ 184.92	$ 185.32	$ 187.82	$ 190.35	$ 192.92	$ 195.52	$ 198.15
13,000	$ 175.83	$ 178.22	$ 180.64	$ 182.71	$ 183.10	$ 185.60	$ 188.14	$ 190.70	$ 193.31	$ 195.94
13,500	$ 173.97	$ 176.35	$ 178.78	$ 180.84	$ 181.24	$ 183.74	$ 186.27	$ 188.84	$ 191.44	$ 194.07
14,000	$ 172.23	$ 174.62	$ 177.04	$ 179.11	$ 179.50	$ 182.00	$ 184.54	$ 187.11	$ 189.71	$ 192.34
14,500	$ 170.62	$ 173.00	$ 175.43	$ 177.49	$ 177.89	$ 180.39	$ 182.92	$ 185.49	$ 188.09	$ 190.72
15,000	$ 169.11	$ 171.50	$ 173.92	$ 175.99	$ 176.38	$ 178.88	$ 181.42	$ 183.99	$ 186.59	$ 189.22
15,500	$ 167.54	$ 169.93	$ 172.35	$ 174.42	$ 174.81	$ 177.31	$ 179.85	$ 182.42	$ 185.02	$ 187.65
16,000	$ 166.23	$ 168.61	$ 171.04	$ 173.10	$ 173.50	$ 176.00	$ 178.53	$ 181.10	$ 183.70	$ 186.33
16,500	$ 164.99	$ 167.38	$ 169.80	$ 171.87	$ 172.26	$ 174.76	$ 177.30	$ 179.86	$ 182.46	$ 185.10
17,000	$ 163.83	$ 166.21	$ 168.64	$ 170.70	$ 171.10	$ 173.60	$ 176.13	$ 178.70	$ 181.30	$ 183.93

17,500	$ 162.59	$ 164.97	$ 167.40	$ 169.46	$ 169.86	$ 172.36	$ 174.89	$ 177.46	$ 180.06	$ 182.69
18,000	$ 161.56	$ 163.94	$ 166.37	$ 168.43	$ 168.83	$ 171.33	$ 173.86	$ 176.43	$ 179.03	$ 181.66
18,500	$ 160.58	$ 162.97	$ 165.39	$ 167.46	$ 167.85	$ 170.35	$ 172.88	$ 175.45	$ 178.05	$ 180.68
19,000	$ 159.66	$ 162.04	$ 164.46	$ 166.53	$ 166.93	$ 169.43	$ 171.96	$ 174.53	$ 177.13	$ 179.76
19,500	$ 158.65	$ 161.03	$ 163.46	$ 165.52	$ 165.92	$ 168.42	$ 170.95	$ 173.52	$ 176.12	$ 178.75
20,000	$ 157.82	$ 160.20	$ 162.63	$ 164.69	$ 165.09	$ 167.59	$ 170.12	$ 172.69	$ 175.29	$ 177.92
20,500	$ 157.03	$ 159.41	$ 161.84	$ 163.90	$ 164.30	$ 166.80	$ 169.33	$ 171.90	$ 174.50	$ 177.13
21,000	$ 156.28	$ 158.66	$ 161.09	$ 163.15	$ 163.55	$ 166.05	$ 168.58	$ 171.15	$ 173.75	$ 176.38
21,500	$ 155.56	$ 157.95	$ 160.37	$ 162.44	$ 162.83	$ 165.33	$ 167.86	$ 170.43	$ 173.03	$ 175.66
22,000	$ 154.76	$ 157.15	$ 159.57	$ 161.64	$ 162.03	$ 164.53	$ 167.07	$ 169.63	$ 172.23	$ 174.87
22,500	$ 154.11	$ 156.50	$ 158.92	$ 160.99	$ 161.38	$ 163.88	$ 166.41	$ 168.98	$ 171.58	$ 174.22
23,000	$ 153.49	$ 155.87	$ 158.30	$ 160.36	$ 160.76	$ 163.26	$ 165.79	$ 168.36	$ 170.96	$ 173.59
23,500	$ 152.89	$ 155.28	$ 157.70	$ 159.77	$ 160.16	$ 162.66	$ 165.19	$ 167.76	$ 170.36	$ 172.99

24,000	$ 152.21	$ 154.60	$ 157.02	$ 159.09	$ 159.49	$ 161.98	$ 164.52	$ 167.09	$ 169.69	$ 172.32
24,500	$ 151.67	$ 154.05	$ 156.48	$ 158.54	$ 158.94	$ 161.44	$ 163.97	$ 166.54	$ 169.14	$ 171.77
25,000	$ 151.14	$ 153.53	$ 155.95	$ 158.02	$ 158.41	$ 160.91	$ 163.45	$ 166.02	$ 168.62	$ 171.25
25,500	$ 150.64	$ 153.02	$ 155.45	$ 157.51	$ 157.91	$ 160.41	$ 162.94	$ 165.51	$ 168.11	$ 170.74
26,000	$ 150.06	$ 152.44	$ 154.87	$ 156.93	$ 157.33	$ 159.83	$ 162.36	$ 164.93	$ 167.53	$ 170.16
26,500	$ 149.59	$ 151.98	$ 154.40	$ 156.47	$ 156.87	$ 159.36	$ 161.90	$ 164.47	$ 167.07	$ 169.70
27,000	$ 149.15	$ 151.53	$ 153.96	$ 156.02	$ 156.42	$ 158.92	$ 161.45	$ 164.02	$ 166.62	$ 169.25
27,500	$ 148.72	$ 151.10	$ 153.52	$ 155.59	$ 155.99	$ 158.49	$ 161.02	$ 163.59	$ 166.19	$ 168.82
28,000	$ 148.30	$ 150.68	$ 153.11	$ 155.17	$ 155.57	$ 158.07	$ 160.60	$ 163.17	$ 165.77	$ 168.40
28,500	$ 147.81	$ 150.20	$ 152.62	$ 154.69	$ 155.08	$ 157.58	$ 160.11	$ 162.68	$ 165.28	$ 167.92
29,000	$ 147.43	$ 149.81	$ 152.23	$ 154.30	$ 154.70	$ 157.20	$ 159.73	$ 162.30	$ 164.90	$ 167.53
29,500	$ 147.05	$ 149.44	$ 151.86	$ 153.93	$ 154.32	$ 156.82	$ 159.36	$ 161.92	$ 164.53	$ 167.16
30,000	$ 146.69	$ 149.08	$ 151.50	$ 153.57	$ 153.96	$ 156.46	$ 159.00	$ 161.56	$ 164.16	$ 166.80

30,500	$ 146.26	$ 148.65	$ 151.07	$ 153.14	$ 153.53	$ 156.03	$ 158.57	$ 161.13	$ 163.73	$ 166.37
31,000	$ 145.93	$ 148.31	$ 150.74	$ 152.80	$ 153.20	$ 155.70	$ 158.23	$ 160.80	$ 163.40	$ 166.03
31,500	$ 145.60	$ 147.99	$ 150.41	$ 152.48	$ 152.87	$ 155.37	$ 157.90	$ 160.47	$ 163.07	$ 165.71
32,000	$ 145.29	$ 147.67	$ 150.09	$ 152.16	$ 152.56	$ 155.06	$ 157.59	$ 160.16	$ 162.76	$ 165.39
32,500	$ 144.90	$ 147.29	$ 149.71	$ 151.78	$ 152.17	$ 154.67	$ 157.21	$ 159.78	$ 162.38	$ 165.01
33,000	$ 144.61	$ 146.99	$ 149.42	$ 151.48	$ 151.88	$ 154.38	$ 156.91	$ 159.48	$ 162.08	$ 164.71
33,500	$ 144.32	$ 146.71	$ 149.13	$ 151.20	$ 151.59	$ 154.09	$ 156.63	$ 159.19	$ 161.79	$ 164.43
34,000	$ 144.04	$ 146.43	$ 148.85	$ 150.92	$ 151.32	$ 153.81	$ 156.35	$ 158.92	$ 161.52	$ 164.15
34,500	$ 143.77	$ 146.16	$ 148.58	$ 150.65	$ 151.05	$ 153.54	$ 156.08	$ 158.65	$ 161.25	$ 163.88
35,000	$ 143.44	$ 145.83	$ 148.25	$ 150.32	$ 150.71	$ 153.21	$ 155.75	$ 158.31	$ 160.91	$ 163.55
35,500	$ 143.19	$ 145.57	$ 148.00	$ 150.06	$ 150.46	$ 152.96	$ 155.49	$ 158.06	$ 160.66	$ 163.29
36,000	$ 142.94	$ 145.33	$ 147.75	$ 149.82	$ 150.21	$ 152.71	$ 155.25	$ 157.81	$ 160.41	$ 163.05
36,500	$ 142.70	$ 145.09	$ 147.51	$ 149.58	$ 149.97	$ 152.47	$ 155.01	$ 157.57	$ 160.17	$ 162.81

37,000	$ 142.40	$ 144.79	$ 147.21	$ 149.28	$ 149.67	$ 152.17	$ 154.70	$ 157.27	$ 159.87	$ 162.51

Appendix 4: Sensitivity Analysis of WACC / Capture Volume on Net LCOC (All Benefits Considered)

Capture Volume	WACC									
$ 44.92	7.00 %	7.50%	8.00%	8.42%	8.50%	9.00%	9.50%	10.00 %	10.50%	11.00 %
12,500	$ 38.05	$ 40.43	$ 42.86	$ 44.92	$ 45.32	$ 47.82	$ 50.35	$ 52.92	$ 55.52	$ 58.15
13,000	$ 38.91	$ 41.29	$ 43.72	$ 45.78	$ 46.18	$ 48.68	$ 51.21	$ 53.78	$ 56.38	$ 59.01
13,500	$ 39.89	$ 42.28	$ 44.70	$ 46.77	$ 47.16	$ 49.66	$ 52.20	$ 54.76	$ 57.36	$ 60.00
14,000	$ 40.80	$ 43.19	$ 45.61	$ 47.68	$ 48.08	$ 50.57	$ 53.11	$ 55.68	$ 58.28	$ 60.91
14,500	$ 41.65	$ 44.04	$ 46.46	$ 48.53	$ 48.93	$ 51.42	$ 53.96	$ 56.53	$ 59.13	$ 61.76
15,000	$ 42.45	$ 44.83	$ 47.26	$ 49.32	$ 49.72	$ 52.22	$ 54.75	$ 57.32	$ 59.92	$ 62.55
15,500	$ 43.03	$ 45.41	$ 47.84	$ 49.90	$ 50.30	$ 52.80	$ 55.33	$ 57.90	$ 60.50	$ 63.13
16,000	$ 43.73	$ 46.11	$ 48.54	$ 50.60	$ 51.00	$ 53.50	$ 56.03	$ 58.60	$ 61.20	$ 63.83
16,500	$ 44.39	$ 46.77	$ 49.19	$ 51.26	$ 51.66	$ 54.16	$ 56.69	$ 59.26	$ 61.86	$ 64.49

17,000	$ 45.00	$ 47.39	$ 49.81	$ 51.88	$ 52.28	$ 54.77	$ 57.31	$ 59.88	$ 62.48	$ 65.11
17,500	$ 45.45	$ 47.83	$ 50.25	$ 52.32	$ 52.72	$ 55.22	$ 57.75	$ 60.32	$ 62.92	$ 65.55
18,000	$ 46.00	$ 48.39	$ 50.81	$ 52.88	$ 53.27	$ 55.77	$ 58.30	$ 60.87	$ 63.47	$ 66.11
18,500	$ 46.53	$ 48.91	$ 51.34	$ 53.40	$ 53.80	$ 56.30	$ 58.83	$ 61.40	$ 64.00	$ 66.63
19,000	$ 47.02	$ 49.41	$ 51.83	$ 53.90	$ 54.30	$ 56.79	$ 59.33	$ 61.90	$ 64.50	$ 67.13
19,500	$ 47.37	$ 49.75	$ 52.18	$ 54.24	$ 54.64	$ 57.14	$ 59.67	$ 62.24	$ 64.84	$ 67.47
20,000	$ 47.82	$ 50.20	$ 52.63	$ 54.69	$ 55.09	$ 57.59	$ 60.12	$ 62.69	$ 65.29	$ 67.92
20,500	$ 48.25	$ 50.63	$ 53.06	$ 55.12	$ 55.52	$ 58.02	$ 60.55	$ 63.12	$ 65.72	$ 68.35
21,000	$ 48.66	$ 51.04	$ 53.47	$ 55.53	$ 55.93	$ 58.43	$ 60.96	$ 63.53	$ 66.13	$ 68.76
21,500	$ 49.05	$ 51.43	$ 53.86	$ 55.92	$ 56.32	$ 58.82	$ 61.35	$ 63.92	$ 66.52	$ 69.15
22,000	$ 49.31	$ 51.69	$ 54.12	$ 56.18	$ 56.58	$ 59.08	$ 61.61	$ 64.18	$ 66.78	$ 69.41
22,500	$ 49.67	$ 52.05	$ 54.48	$ 56.54	$ 56.94	$ 59.44	$ 61.97	$ 64.54	$ 67.14	$ 69.77

23,000	$ 50.01	$ 52.39	$ 54.82	$ 56.88	$ 57.28	$ 59.78	$ 62.31	$ 64.88	$ 67.48	$ 70.11
23,500	$ 50.34	$ 52.72	$ 55.15	$ 57.21	$ 57.61	$ 60.11	$ 62.64	$ 65.21	$ 67.81	$ 70.44
24,000	$ 50.55	$ 52.93	$ 55.36	$ 57.42	$ 57.82	$ 60.32	$ 62.85	$ 65.42	$ 68.02	$ 70.65
24,500	$ 50.85	$ 53.24	$ 55.66	$ 57.73	$ 58.12	$ 60.62	$ 63.16	$ 65.72	$ 68.32	$ 70.96
25,000	$ 51.14	$ 53.53	$ 55.95	$ 58.02	$ 58.41	$ 60.91	$ 63.45	$ 66.02	$ 68.62	$ 71.25
25,500	$ 51.42	$ 53.81	$ 56.23	$ 58.30	$ 58.69	$ 61.19	$ 63.73	$ 66.30	$ 68.90	$ 71.53
26,000	$ 51.60	$ 53.98	$ 56.41	$ 58.47	$ 58.87	$ 61.37	$ 63.90	$ 66.47	$ 69.07	$ 71.70
26,500	$ 51.86	$ 54.24	$ 56.67	$ 58.73	$ 59.13	$ 61.63	$ 64.16	$ 66.73	$ 69.33	$ 71.96
27,000	$ 52.11	$ 54.49	$ 56.92	$ 58.98	$ 59.38	$ 61.88	$ 64.41	$ 66.98	$ 69.58	$ 72.21
27,500	$ 52.35	$ 54.74	$ 57.16	$ 59.23	$ 59.62	$ 62.12	$ 64.66	$ 67.22	$ 69.82	$ 72.46
28,000	$ 52.59	$ 54.97	$ 57.39	$ 59.46	$ 59.86	$ 62.36	$ 64.89	$ 67.46	$ 70.06	$ 72.69
28,500	$ 52.72	$ 55.11	$ 57.53	$ 59.60	$ 59.99	$ 62.49	$ 65.03	$ 67.60	$ 70.20	$ 72.83

29,000	$ 52.94	$ 55.33	$ 57.75	$ 59.82	$ 60.21	$ 62.71	$ 65.25	$ 67.81	$ 70.41	$ 73.05
29,500	$ 53.15	$ 55.54	$ 57.96	$ 60.03	$ 60.43	$ 62.92	$ 65.46	$ 68.03	$ 70.63	$ 73.26
30,000	$ 53.36	$ 55.74	$ 58.17	$ 60.23	$ 60.63	$ 63.13	$ 65.66	$ 68.23	$ 70.83	$ 73.46
30,500	$ 53.47	$ 55.86	$ 58.28	$ 60.35	$ 60.75	$ 63.24	$ 65.78	$ 68.35	$ 70.95	$ 73.58
31,000	$ 53.67	$ 56.05	$ 58.48	$ 60.54	$ 60.94	$ 63.44	$ 65.97	$ 68.54	$ 71.14	$ 73.77
31,500	$ 53.85	$ 56.24	$ 58.66	$ 60.73	$ 61.13	$ 63.62	$ 66.16	$ 68.73	$ 71.33	$ 73.96
32,000	$ 54.04	$ 56.42	$ 58.84	$ 60.91	$ 61.31	$ 63.81	$ 66.34	$ 68.91	$ 71.51	$ 74.14
32,500	$ 54.13	$ 56.52	$ 58.94	$ 61.01	$ 61.41	$ 63.90	$ 66.44	$ 69.01	$ 71.61	$ 74.24
33,000	$ 54.31	$ 56.69	$ 59.11	$ 61.18	$ 61.58	$ 64.08	$ 66.61	$ 69.18	$ 71.78	$ 74.41
33,500	$ 54.47	$ 56.86	$ 59.28	$ 61.35	$ 61.74	$ 64.24	$ 66.78	$ 69.34	$ 71.94	$ 74.58
34,000	$ 54.63	$ 57.02	$ 59.44	$ 61.51	$ 61.90	$ 64.40	$ 66.94	$ 69.50	$ 72.11	$ 74.74
34,500	$ 54.79	$ 57.17	$ 59.60	$ 61.66	$ 62.06	$ 64.56	$ 67.09	$ 69.66	$ 72.26	$ 74.89

35,000	$ 54.87	$ 57.26	$ 59.68	$ 61.75	$ 62.14	$ 64.64	$ 67.17	$ 69.74	$ 72.34	$ 74.97
35,500	$ 55.02	$ 57.40	$ 59.83	$ 61.89	$ 62.29	$ 64.79	$ 67.32	$ 69.89	$ 72.49	$ 75.12
36,000	$ 55.16	$ 57.55	$ 59.97	$ 62.04	$ 62.44	$ 64.93	$ 67.47	$ 70.04	$ 72.64	$ 75.27
36,500	$ 55.30	$ 57.69	$ 60.11	$ 62.18	$ 62.58	$ 65.07	$ 67.61	$ 70.18	$ 72.78	$ 75.41
37,000	$ 55.37	$ 57.76	$ 60.18	$ 62.25	$ 62.65	$ 65.14	$ 67.68	$ 70.25	$ 72.85	$ 75.48

Appendix 5: Scenarios at Scale Data Table

	Non Seasonal	Base Viticulture	C1	C2	C3	Net LCOC
12,500	$78.86	$184.92	$104.92	$130.92	$178.92	$44.92
14,500	$71.55	$177.49	$108.53	$122.67	$172.32	$48.53
16,500	$65.86	$171.87	$111.26	$116.41	$167.32	$51.26
18,500	$61.41	$167.46	$113.40	$111.51	$163.40	$53.40
20,500	$57.94	$163.90	$115.12	$107.56	$160.25	$55.12
22,500	$54.98	$160.99	$116.54	$104.32	$157.65	$56.54
24,500	$52.61	$158.54	$117.73	$101.60	$155.48	$57.73
26,500	$50.50	$156.47	$118.73	$99.30	$153.64	$58.73
28,500	$48.77	$154.69	$119.60	$97.32	$152.05	$59.60
30,500	$47.19	$153.14	$120.35	$95.60	$150.68	$60.35
32,500	$45.80	$151.78	$121.01	$94.09	$149.47	$61.01
34,500	$44.65	$150.65	$121.66	$92.82	$148.48	$61.66
36,500	$43.55	$149.58	$122.18	$91.63	$147.52	$62.18
38,500	$42.63	$148.61	$122.64	$90.56	$146.67	$62.64

40,500	$41.75	$147.75	$123.06	$89.60	$145.90	$63.06
42,500	$41.00	$146.96	$123.43	$88.73	$145.20	$63.43
44,500	$40.27	$146.25	$123.78	$87.93	$144.56	$63.78
46,500	$39.65	$145.60	$124.09	$87.21	$143.98	$64.09
48,500	$39.03	$145.00	$124.38	$86.54	$143.45	$64.38
50,500	$38.46	$144.44	$124.64	$85.93	$142.96	$64.64
52,500	$37.98	$143.93	$124.89	$85.36	$142.51	$64.89
54,500	$37.49	$143.46	$125.11	$84.84	$142.09	$65.11
56,500	$37.08	$143.02	$125.32	$84.35	$141.70	$65.32
58,500	$36.65	$142.61	$125.52	$83.90	$141.33	$65.52
60,500	$36.30	$142.27	$125.74	$83.51	$141.03	$65.74
62,500	$35.93	$141.91	$125.91	$83.11	$140.71	$65.91
64,500	$35.58	$141.58	$126.07	$82.74	$140.42	$66.07
66,500	$35.29	$141.26	$126.22	$82.39	$140.13	$66.22
68,500	$34.97	$140.96	$126.37	$82.06	$139.87	$66.37

70,500	$34.72	$140.68	$126.50	$81.75	$139.62	$66.50
72,500	$34.44	$140.42	$126.62	$81.45	$139.38	$66.62
74,500	$34.21	$140.17	$126.74	$81.17	$139.16	$66.74
76,500	$33.96	$139.93	$126.86	$80.91	$138.95	$66.86
78,500	$33.72	$139.70	$126.96	$80.66	$138.75	$66.96
80,500	$33.53	$139.49	$127.07	$80.42	$138.56	$67.07
82,500	$33.31	$139.28	$127.16	$80.19	$138.37	$67.16
84,500	$33.14	$139.09	$127.25	$79.98	$138.20	$67.25
86,500	$32.94	$138.93	$127.37	$79.80	$138.07	$67.37
88,500	$32.78	$138.75	$127.46	$79.60	$137.91	$67.46
90,500	$32.60	$138.58	$127.54	$79.41	$137.76	$67.54
92,500	$32.43	$138.42	$127.61	$79.23	$137.61	$67.61
94,500	$32.29	$138.27	$127.68	$79.06	$137.47	$67.68
96,500	$32.13	$138.12	$127.75	$78.89	$137.34	$67.75
98,500	$32.01	$137.97	$127.82	$78.74	$137.21	$67.82

100,500	$31.86	$137.84	$127.89	$78.58	$137.09	$67.89
102,500	$31.74	$137.70	$127.95	$78.44	$136.97	$67.95
104,500	$31.61	$137.58	$128.01	$78.29	$136.86	$68.01
106,500	$31.48	$137.45	$128.06	$78.16	$136.75	$68.06
108,500	$31.37	$137.34	$128.12	$78.03	$136.65	$68.12
110,500	$31.25	$137.22	$128.17	$77.90	$136.54	$68.17
112,500	$31.16	$137.14	$128.25	$77.80	$136.47	$68.25
114,500	$31.04	$137.03	$128.30	$77.68	$136.37	$68.30
116,500	$30.95	$136.93	$128.34	$77.57	$136.28	$68.34
118,500	$30.85	$136.83	$128.39	$77.46	$136.20	$68.39
120,500	$30.74	$136.73	$128.43	$77.36	$136.11	$68.43
122,500	$30.67	$136.64	$128.48	$77.25	$136.03	$68.48
124,500	$30.57	$136.55	$128.52	$77.15	$135.95	$68.52
126,500	$30.49	$136.46	$128.56	$77.06	$135.87	$68.56
128,500	$30.40	$136.38	$128.60	$76.96	$135.80	$68.60

130,500	$30.33	$136.30	$128.64	$76.87	$135.72	$68.64
132,500	$30.25	$136.22	$128.67	$76.79	$135.65	$68.67
134,500	$30.17	$136.14	$128.71	$76.70	$135.58	$68.71
136,500	$30.10	$136.07	$128.74	$76.62	$135.52	$68.74
138,500	$30.02	$136.00	$128.78	$76.54	$135.45	$68.78
140,500	$29.97	$135.94	$128.83	$76.48	$135.41	$68.83
142,500	$29.89	$135.87	$128.86	$76.40	$135.35	$68.86
144,500	$29.84	$135.81	$128.89	$76.33	$135.29	$68.89
146,500	$29.76	$135.74	$128.92	$76.26	$135.23	$68.92
148,500	$29.70	$135.68	$128.95	$76.19	$135.18	$68.95
150,500	$29.64	$135.62	$128.97	$76.12	$135.12	$68.97
152,500	$29.58	$135.56	$129.00	$76.05	$135.07	$69.00
154,500	$29.53	$135.50	$129.03	$75.99	$135.02	$69.03
156,500	$29.47	$135.44	$129.05	$75.92	$134.97	$69.05
158,500	$29.42	$135.39	$129.08	$75.86	$134.92	$69.08

160,500	$29.36	$135.34	$129.10	$75.80	$134.87	$69.10
162,500	$29.31	$135.28	$129.13	$75.74	$134.82	$69.13
164,500	$29.26	$135.23	$129.15	$75.69	$134.78	$69.15
166,500	$29.21	$135.20	$129.19	$75.65	$134.75	$69.19
168,500	$29.17	$135.15	$129.21	$75.59	$134.70	$69.21
170,500	$29.12	$135.10	$129.23	$75.54	$134.66	$69.23
172,500	$29.08	$135.05	$129.26	$75.49	$134.62	$69.26
174,500	$29.03	$135.01	$129.28	$75.44	$134.58	$69.28
176,500	$28.98	$134.96	$129.30	$75.39	$134.54	$69.30
178,500	$28.94	$134.92	$129.32	$75.34	$134.50	$69.32
180,500	$28.90	$134.88	$129.34	$75.29	$134.46	$69.34
182,500	$28.86	$134.83	$129.35	$75.24	$134.42	$69.35
184,500	$28.82	$134.79	$129.37	$75.20	$134.39	$69.37
186,500	$28.79	$134.75	$129.39	$75.16	$134.35	$69.39
188,500	$28.74	$134.71	$129.41	$75.11	$134.32	$69.41

190,500	$28.71	$134.68	$129.43	$75.07	$134.28	$69.43
192,500	$28.67	$134.65	$129.46	$75.04	$134.26	$69.46
194,500	$28.63	$134.61	$129.47	$75.00	$134.23	$69.47
196,500	$28.60	$134.58	$129.49	$74.96	$134.20	$69.49
198,500	$28.56	$134.54	$129.50	$74.92	$134.16	$69.50
200,500	$28.53	$134.51	$129.52	$74.88	$134.13	$69.52
202,500	$28.50	$134.47	$129.54	$74.84	$134.10	$69.54
204,500	$28.47	$134.44	$129.55	$74.81	$134.07	$69.55
206,500	$28.43	$134.41	$129.56	$74.77	$134.04	$69.56
208,500	$28.40	$134.38	$129.58	$74.74	$134.02	$69.58
210,500	$28.37	$134.34	$129.59	$74.70	$133.99	$69.59
212,500	$28.34	$134.31	$129.61	$74.67	$133.96	$69.61
214,500	$28.32	$134.28	$129.62	$74.63	$133.93	$69.62
216,500	$28.28	$134.25	$129.63	$74.60	$133.91	$69.63
218,500	$28.26	$134.24	$129.66	$74.58	$133.89	$69.66

220,500	$28.23	$134.21	$129.67	$74.55	$133.87	$69.67
222,500	$28.20	$134.18	$129.68	$74.52	$133.84	$69.68
224,500	$28.17	$134.15	$129.70	$74.48	$133.82	$69.70
226,500	$28.14	$134.12	$129.71	$74.45	$133.79	$69.71
228,500	$28.12	$134.10	$129.72	$74.42	$133.77	$69.72
230,500	$28.09	$134.07	$129.73	$74.40	$133.74	$69.73
232,500	$28.07	$134.04	$129.74	$74.37	$133.72	$69.74
234,500	$28.05	$134.02	$129.75	$74.34	$133.70	$69.75
236,500	$28.02	$133.99	$129.77	$74.31	$133.68	$69.77
238,500	$28.00	$133.97	$129.78	$74.28	$133.65	$69.78
240,500	$27.97	$133.95	$129.79	$74.26	$133.63	$69.79
242,500	$27.95	$133.92	$129.80	$74.23	$133.61	$69.80
244,500	$27.93	$133.91	$129.82	$74.21	$133.60	$69.82
246,500	$27.91	$133.89	$129.83	$74.19	$133.58	$69.83
248,500	$27.88	$133.86	$129.84	$74.16	$133.56	$69.84

250,500	$27.86	$133.84	$129.85	$74.14	$133.54	$69.85
252,500	$27.84	$133.82	$129.86	$74.12	$133.52	$69.86
254,500	$27.82	$133.80	$129.87	$74.09	$133.50	$69.87
256,500	$27.80	$133.78	$129.88	$74.07	$133.48	$69.88
258,500	$27.78	$133.75	$129.89	$74.04	$133.46	$69.89
260,500	$27.76	$133.73	$129.89	$74.02	$133.45	$69.89
262,500	$27.74	$133.71	$129.90	$74.00	$133.43	$69.90
264,500	$27.72	$133.69	$129.91	$73.98	$133.41	$69.91
266,500	$27.70	$133.67	$129.92	$73.95	$133.39	$69.92
268,500	$27.68	$133.65	$129.93	$73.93	$133.37	$69.93
270,500	$27.67	$133.63	$129.94	$73.91	$133.36	$69.94
272,500	$27.64	$133.62	$129.96	$73.90	$133.35	$69.96
274,500	$27.63	$133.61	$129.96	$73.88	$133.33	$69.96
276,500	$27.61	$133.59	$129.97	$73.86	$133.32	$69.97
278,500	$27.59	$133.57	$129.98	$73.84	$133.30	$69.98

280,500	$27.58	$133.55	$129.99	$73.82	$133.28	$69.99
282,500	$27.56	$133.53	$129.99	$73.80	$133.27	$69.99
284,500	$27.54	$133.52	$130.00	$73.78	$133.25	$70.00
286,500	$27.52	$133.50	$130.01	$73.76	$133.24	$70.01
288,500	$27.51	$133.48	$130.02	$73.74	$133.22	$70.02
290,500	$27.49	$133.47	$130.02	$73.72	$133.21	$70.02
292,500	$27.47	$133.45	$130.03	$73.71	$133.19	$70.03
294,500	$27.46	$133.43	$130.04	$73.69	$133.18	$70.04
296,500	$27.44	$133.42	$130.04	$73.67	$133.16	$70.04
298,500	$27.43	$133.41	$130.06	$73.66	$133.16	$70.06
300,500	$27.41	$133.39	$130.07	$73.64	$133.14	$70.07
302,500	$27.40	$133.38	$130.07	$73.63	$133.13	$70.07
304,500	$27.39	$133.36	$130.08	$73.61	$133.12	$70.08
306,500	$27.37	$133.35	$130.09	$73.59	$133.10	$70.09
308,500	$27.36	$133.33	$130.09	$73.58	$133.09	$70.09

310,500	$27.34	$133.32	$130.10	$73.56	$133.08	$70.10
312,500	$27.33	$133.30	$130.10	$73.54	$133.06	$70.10
314,500	$27.32	$133.29	$130.11	$73.53	$133.05	$70.11
316,500	$27.31	$133.28	$130.12	$73.51	$133.04	$70.12
318,500	$27.29	$133.26	$130.12	$73.50	$133.03	$70.12
320,500	$27.27	$133.25	$130.13	$73.48	$133.01	$70.13
322,500	$27.26	$133.24	$130.13	$73.47	$133.00	$70.13
324,500	$27.25	$133.23	$130.15	$73.46	$133.00	$70.15
326,500	$27.24	$133.22	$130.15	$73.45	$132.99	$70.15
328,500	$27.22	$133.20	$130.16	$73.43	$132.98	$70.16
330,500	$27.22	$133.19	$130.16	$73.42	$132.96	$70.16
332,500	$27.20	$133.18	$130.17	$73.40	$132.95	$70.17
334,500	$27.19	$133.16	$130.18	$73.39	$132.94	$70.18
336,500	$27.18	$133.15	$130.18	$73.38	$132.93	$70.18
338,500	$27.16	$133.14	$130.19	$73.36	$132.92	$70.19

340,500	$27.16	$133.13	$130.19	$73.35	$132.91	$70.19
342,500	$27.14	$133.12	$130.20	$73.33	$132.90	$70.20
344,500	$27.13	$133.10	$130.20	$73.32	$132.89	$70.20
346,500	$27.12	$133.09	$130.21	$73.31	$132.88	$70.21
348,500	$27.11	$133.08	$130.21	$73.30	$132.87	$70.21
350,500	$27.10	$133.08	$130.22	$73.29	$132.86	$70.22
352,500	$27.08	$133.06	$130.23	$73.28	$132.85	$70.23
354,500	$27.08	$133.05	$130.23	$73.26	$132.84	$70.23
356,500	$27.06	$133.04	$130.24	$73.25	$132.83	$70.24
358,500	$27.06	$133.03	$130.24	$73.24	$132.82	$70.24
360,500	$27.04	$133.02	$130.25	$73.23	$132.81	$70.25
362,500	$27.04	$133.01	$130.25	$73.22	$132.80	$70.25

Appendix 6: Use of IA

Master dissertation - AI disclosure

The Master Dissertation, as a rigorous academic endeavor, serves two key purposes: **evaluating your capacity to develop original and well-structured thoughts**, and **strengthening essential cognitive skills**—such as critical thinking, creativity, and intellectual ambition—**demonstrated through reading, writing, and concentration**.

In the age of artificial intelligence, these skills become even more critical, as is respect for **academic integrity**: AI must be used transparently, ethically and responsibly, as a **lever to enrich your thinking**, and not as a substitute for your judgment, intellectual autonomy or the ethical rigor expected in an academic work.

The purpose of this AI disclosure is to help you **analyze your uses of artificial intelligence** throughout your production process, and to **take a step back** from its **contributions**, **its limits** and its **impacts** at each stage of the work.

- This AI disclosure is **mandatory** and must be **included in the appendix** of your production.
- It can be used as a **support for the oral evaluation**, and particularly on criteria relating to the use of AI.
- **No use of generative AI is allowed** to write this AI disclosure: it must reflect **your own critical analysis** and your ability to take a personal look at your practices.

1.

Reminder of the AI's authorized use framework

1. **Responsibility** – The student is fully responsible for the assignments submitted. The data generated by an AI must be **verified, interpreted and adjusted**.

2. **Transparency** – The tools and aids used must be **clearly mentioned** when they have contributed to the production of the work, in accordance with **academic integrity**.

3. **Authenticity** – The student's work must make it possible to evaluate **the skills and knowledge actually acquired** by the student, both in the result and in the process and method used to achieve it.

4. **Traceability** – **Exchanges with AI tools** must be **kept until the results are announced** (except for purely linguistic uses: correction, reformulation, synonyms, etc.) in order to allow for possible verifications.

5. **Confidentiality** – It is forbidden to submit **personal or sensitive data to an AI**. It is forbidden to enter **an organization's internal or confidential data into AI without its explicit permission.**
6. **Plagiarism –** It is the act of appropriating someone else's work **without citing the source.** It can be a text or a part of a text, but also an image, a photo, data, an original idea. Any information, ideas, or content from others (including via an AI) must be **cited and referenced correctly**.

I have read and I accept

Declaration of use of AI
2.
Title of the master dissertation
3.
Name of your tutor
4.
Email of your tutor
5.
Your use of AI
Check the box that corresponds to your use of AI
"AI tools were used during the design and/or writing of this production, in accordance with all the principles and modalities mentioned above."
"No AI tools were used during the design and/or writing of this production."
If you've used AI tools
1) Check off the phases during which you used AI tools.
2) For each phase checked, describe the tools and uses.
Example:
- DeepL for translating paragraphs from some referenced articles to make them easier to understand and use in this dissertation.
- ChatGPT to propose alternative formulations for a limited number of paragraphs; ChatGPT's proposals were then adapted to the style and spirit of this thesis.
3) **If required, insert a proof of your choice that illustrates your usage (prompt and result generated in the form of a screenshot)**

Note: Data collection is not included in the possible uses detailed in the table below because the use of AI is prohibited at this stage. It is strictly forbidden to use AI to invent fake data.
6.
Identify and explore the topic
Yes, I've used AI
No, I haven't
7.
Identify and explore the topic
Briefly describe your main uses and tools used
8.
Identify sources / conduct a literature review
Yes, I've used AI
No, I haven't
9.
Identify sources / conduct a literature review
Briefly describe your main uses and tools used
10.
Literature review - Proof of your choice (Non-anonymous question)
Insert in the form of a screenshot a proof of your choice that illustrates your usage (prompt and result generated)

Spreadsheet Formula to Visual Equation_Eily Kate IRWIN.pdf
11.
Translating sources
Yes, I've used AI
No, I haven't
12.
Generate ideas or challenge yourself in your ideas.
Yes, I've used AI
No, I haven't
13.
Formulate research questions or hypotheses
Yes, I've used AI
No, I haven't
14.
Analyze the data
Yes, I've used AI
No, I haven't
15.
Interpret and discuss results
Yes, I've used AI
No, I haven't
16.
Structure the writing of the dissertation
Yes, I've used AI
No, I haven't
17.
Produce a text or a visual
Yes, I've used AI
No, I haven't
18.
Produce a text or a visual
Briefly describe your main uses and tools used
19.
Improving the wording of a text
Yes, I've used AI
No, I haven't
20.
Correct the spelling, grammar, syntax of a text
Yes, I've used AI
No, I haven't
21.
Other
Yes, I've used AI

No, I haven't

22.

Interests and limitations

Explain in a few lines the main advantages and limitations of the tools used. Based on your experience, what recommendations would you make to a future student who would carry out a similar production using AI tools?