NSW Oyster Industry: 2022-23 Carbon Footprint Estimate

Non-Technical Report: June 2025

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EXECUTIVE SUMMARY

The NSW oyster industry operates with a very low carbon footprint, making it one of the lowest carbon food proteins produced. The estimated total statewide emissions from oyster farming in NSW in 2022/23 were **2,640 t CO_2e,** equating to **0.93 kg CO_2e / kg product harvested**, and **3.75 kg CO_2e / 100g protein**. If these emissions were offset through the use of Australian Carbon Credit Units at $34 / t CO_2e, it would require an investment of just ~$100,000, translating to a cost of only 1.5 cents per dozen oysters sold.

Carbon audits were conducted with twenty-five representative oyster farms across NSW to assess emissions sources and explore mitigation strategies. Results revealed that fuel consumption accounted for over 75% of industry emissions, with unleaded petrol in outboard engines identified as the dominant contributor. The purchase of electricity made up approximately 19%, though uptake of solar panels and battery storage presents an opportunity for reducing reliance on grid power.

Several recommendations have been proposed to enhance industry sustainability:

- **Adoption of solar systems:** Farmers should leverage government subsidies for solar installations and battery storage to improve energy resilience.
- **Outboard trials:** Pilot projects to evaluate the viability of electric and hydrogen-powered outboards, testing their efficiency, range, and practicality for oyster farming.
- **Supply-chain emissions tracking:** Improved emissions accounting for hatcheries, nurseries and farming infrastructure would enhance the accuracy of carbon audits, ensuring a more complete picture of industry-wide emissions.
- **Life-cycle assessment of oysters:** Research is required to accurately understand carbon flows within oyster production, including shell biomineralisation and dissolution.
- **Climate Active certification:** Given the industry's low emissions, farmers could explore third-party certification, while engaging with Climate Active to determine the feasibility of sector-wide certification.

Beyond carbon neutrality, oyster farming also delivers significant ecosystem benefits, particularly nutrient removal. Oysters naturally assimilate nitrogen and phosphorus, with the industry removing approximately **15,444 kg of nitrogen** and **1,909 kg of phosphorus** in 2022/23. The financial value of this nutrient removal, benchmarked against the Reef Credit Scheme, equates to an estimated **$1.74 million.**

There is strong merit in trialing a nutrient trading scheme to leverage this service commercially. NSW regulation and policy permits flexible environmental offsets, and collaboration with regulators and emission producers could pave the way for market-based incentives.

In summary, the NSW oyster industry has the opportunity to strengthen its sustainability credentials and diversify revenue streams. Investment in renewable energy, emissions tracking, and certification will help future-proof the sector while highlighting its role in carbon neutrality and environmental stewardship.

ABBREVIATIONS

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ACCU	Australian Carbon Credit Unit
AIA	Agricultural Innovation Australia
ALCAS	Australian Life Cycle Assessment Society
Aus LCI	Australian Lifecycles Database
CO_2e	Carbon dioxide equivalent
DIN	Dissolved inorganic nitrogen
FRDC	Fisheries Research Development Corporation
FSANZ	Food Standards Australia New Zealand
FSC	Forestry Stewardship Council
FY	Financial year
GHG	Greenhouse Gas
GWP_{100}	100 yr Global Warming Potential
HDPE	High density polyethylene
LGA	Local Government Authority
MLA	Meat and Livestock Association
NRM	Natural Resource Management
NSW	New South Wales
NSW DPIRD	NSW Department of Primary Industries & Regional Development
NSW EPA	NSW Environment Protection Authority
NSW FA	NSW Farmers Association
PAC	Pacific oyster (*Magallana gigas*)
pCO_2	Partial pressure of carbon dioxide
PES	Payments for ecosystem services
PP	Polypropylene
PV	Photovoltaic
RCS	Reef Credit Scheme
SBT	Science Based Targets
SBTi	Science Based Targets Initiative
SME's	Small and Medium Enterprises
SRES	Small-scale Renewable Energy Scheme
SRO	Sydney rock oyster (*Saccostrea glomerata*)
TN	Total nitrogen
TP	Total phosphorus

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1 INTRODUCTION

After the natural disasters of 2021 and 2022, the NSW Farmers Association obtained funding through the Australian and NSW Governments' Storm and Flood Industry Recovery Program to strengthen the preparedness and resilience of the NSW Oyster Industry against future events. This funding supported a program of initiatives, leading to the development of resources to enhance disaster preparedness and materials to aid market development. These activities are outlined in Box 1, with further details available at www.nswfarmers.org.au. This report relates to activity iv) listed below.

Box 1. Overview of activities delivered by NSW Farmers under the Storm and Flood Industry Recovery Program.

i. Development and extension of a disaster handbook contextualised for the NSW oyster industry.
ii. Establishment of a network of emergency oyster relay areas, allowing temporary relocation of stock to lower-risk locations within an estuary, outside of farmers' lease holdings.
iii. Creation and distribution of oyster promotional materials, including consumer-focused educational videos and nutritional information brochures.
iv. Conducting carbon, nitrogen, and phosphorus farm audits, along with estimating state-level emissions.

In 2022, the consultancy Nine-Squared conducted a study examining carbon-related opportunities for the Australian oyster industry (Nine-Squared 2022). The findings suggest that the Australian Government's Emissions Reduction Fund (ERF) is unlikely to prioritise oyster aquaculture for the development of methods that allow the industry to generate carbon credits. This is due to several factors, including ongoing scientific uncertainty surrounding shell carbon (discussed in section 2.1) and the higher potential of other ecosystems - such as wetlands, mangroves, and saltmarshes - to sequester carbon on a larger and more permanent scale. Consequently, oyster farmers should not expect financial compensation for the carbon they may perceive as being sequestered in their product.

Nine-Squared concluded that the most significant short- to medium-term carbon opportunities for the oyster industry lie in achieving carbon-neutral certification. This certification could offer dual benefits by providing a competitive market advantage and enhancing the industry's sustainability reputation. By showcasing their role as responsible users of public waterways, oyster farmers could strengthen their social license to operate.

To date, uptake of carbon neutral certification within the Australian oyster industry has been slow. Due to recent supply disruptions and a strong market (in which demand consistently exceeds supply), certification has not been a priority for the industry. It has also not been demanded by the supply-chain to enable market access. In addition, the veracity of the Climate Active scheme used to certify an organisation as carbon neutral has been called into question with numerous organisations withdrawing from the scheme (The Conversation 2025). Nevertheless, there is growing societal, regulatory, and consumer pressure for industries to adopt sustainable, low-carbon production systems. As national oyster production scales up, carbon-neutral certification may eventually become a supply-chain requirement.

Recognising this opportunity, NSW Farmers Association initiated a project providing free carbon audits to oyster growers in NSW. These informal assessments were designed to:

- identify the primary sources of greenhouse gas emissions on farm,
- present practical strategies to reduce emissions, and
- estimate the cost of offsetting emissions.

NSW Farmers collaborated with Blueshift Consulting, a firm specialising in 'blue carbon', to develop audit tools. Blueshift has experience analysing energy use and carbon emissions in the Australian aquaculture sector, having created self-assessment tools through a 2020 Fisheries Research Development Corporation (FRDC) project (Blueshift Consulting 2022). Through this current project, the tools were adjusted for the NSW oyster industry, with twenty-four farms electing to participate. Some of these farms requested multi-year audits, allowing them to compare emissions over time. This helped to reveal the impact of changes in farming practice and production volume. In total, thirty-one audits were undertaken.

The farms that participated represented a diverse cross-section of the industry, varying in species cultivated, production scale, estuary type, technology use, and adoption of renewable energy. With 243 Class-A aquaculture permit holders registered in NSW in the 2022/23 financial year (NSW DPIRD 2024), this sample provided a solid foundation for analysis and to estimate the carbon footprint of the industry statewide.

Although no formal dedicated decarbonisation projects are currently underway in the oyster industry, understanding emission sources provides valuable insights for future initiatives. Other sectors, such as the red meat industry supported by the Meat & Livestock Association (MLA), have set ambitious targets to achieve carbon neutrality by 2030. While oyster farming is generally considered environmentally sustainable (Schatte Oliver et. al. 2018), the industry is yet to fully capitalise on its low-impact credentials. Failing to act would represent a missed opportunity for both environmental and economic gains.

Although the primary objective of the audits was to assess the net carbon emissions of NSW oyster farms, the collected data also provided other valuable insights. There is growing interest in the ecosystem services offered by oyster production, such as the creation of fish habitat and nutrient removal. These benefits not only enhance the industry's social license but could also pave the way for 'Payments for Ecosystem Services (PES)'. The audits also therefore incorporated estimates of nitrogen and phosphorus removal and the potential financial value of this service.

2 Carbon Science

2.1 Shell Carbon

In 2024, the NSW Department of Primary Industries & Regional Development (NSW DPIRD) provided oyster shells to an analytical laboratory to obtain an accurate analysis of their composition. As shown in Table 1, this work revealed that ~92% of an oyster shell is composed of calcium carbonate ($CaCO_3$).

Property	Value
pH	9.34
Total calcium	328,500 mg/kg
Calcium carbonate	**92.1%**
Total magnesium	2,750 mg/kg
Total nitrogen	1,962 mg/kg
Total phosphorus	318.5 mg/kg
Total sulphur	137.5 mg/kg
Total potassium	35.26 mg/kg
Manganese	27.45 mg/kg
Boron	15.8 mg/kg
Zinc	11.42 mg/kg
Copper	0.81 mg/kg

Table 1. Elemental analysis of oyster shells. Transposed from de Roover (2024).

Calcium carbonate ($CaCO_3$) is a compound made up of one calcium atom (Ca), one carbon atom (C) and three oxygen atoms (O), and so intuitively one would think that oyster shells would be a sink for carbon; removing, concentrating and storing carbon from the surrounding environment. The process of calcification is represented in the equation below, with oysters utilising calcium and bicarbonate ions to produce calcium carbonate.

$$\mathbf{Ca^{2+} + 2HCO^{-}_{3}\text{-} \rightleftharpoons CaCO_3 + CO_2 + H_20}$$

If the carbon sequestered into the shell originated from rapidly cycled carbon pools (such as atmospheric CO_2), there would be a strong case that shell carbon could be considered a carbon sink. Unfortunately, however, this is not the case. Pernet et. al. (2025) claims that the carbon trapped in shell originates from the bicarbonate ions, which are predominantly formed by the chemical weathering of sediments and rocks over tens of thousands of years. Therefore, incorporating this carbon into shell does not prompt short-term CO_2 compensation. Indeed, Pernet et. al (2025), goes on to calculate that only 6% of the bicarbonate pool available to bivalves originate from anthropogenic CO_2.

The equation above also reveals that carbon dioxide is released as a by-product of shell biomineralisation. This release of CO_2 serves to increase the partial pressure of carbon dioxide (pCO_2) in the water, which acts to inhibit the movement of this gas from the atmosphere into the ocean.

The situation is further complicated by the fact that oysters also release carbon into the surrounding water throughout their life cycle. This occurs through processes such as respiration and shell erosion (Figure 1), although respiration is generally not considered an emission in carbon footprint assessments.

There is a research gap concerning the quantitative flow of carbon in relation to oysters in NSW, however studies elsewhere have suggested that when respiration is included as a CO_2 emission, more CO_2 may be released by oysters than they store (Han et. al. 2017). The view that oysters may have a net-positive effect was also supported by a study in New Zealand in 2021, undertaking a life-cycle assessment of Greenshell mussels and Pacific oysters. This study found that shellfish release 0.29 kg CO_2 for every kilogram of shell formed (Thinkstep ANZ 2021).

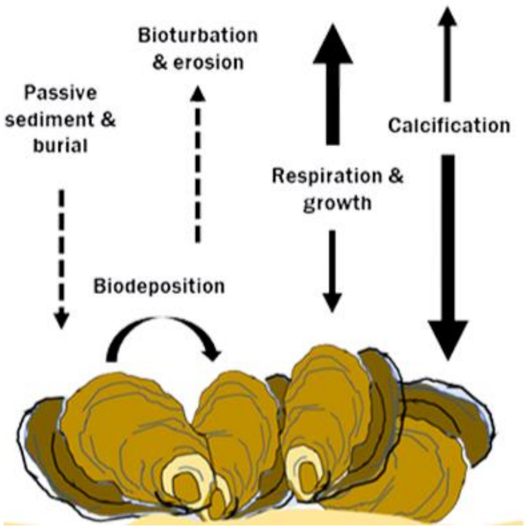

Figure 1. Movement of carbon, showing deposition (downward arrows) and release (upward arrows) (Fodrie et.al. 2017).

Due to the information gaps in relation to carbon flows in Sydney rock oysters in NSW waters, it was decided that shell carbon should be omitted from the footprint analysis provided in this report.

2.2 CO_2E

CO_2e, or carbon dioxide equivalent, is a standardised unit used to express the impact of different greenhouse gases (GHG's) on climate change. Since various GHG's have different 100-year global warming potentials (GWP_{100}), converting the climate change impacts of GHG's to CO_2e allows for a common metric to compare their effects. For example, methane (CH_4) and nitrous oxide (N_2O) are significantly more potent than carbon dioxide (CO_2) in terms of heat-trapping ability. CO_2e converts their impact into an equivalent amount of CO_2.

One kilogram of carbon dioxide equivalent (CO_2e) is a difficult unit to visualise because it's a measure of the warming effect of greenhouse gases, rather than the mass of a substance. To put this into perspective, Carbotech (2022) published a useful table (adapted below in Table 2) demonstrating the significance of 1kg CO_2e. This table shows that 1 kg CO_2e is roughly equivalent to the CO_2 produced by driving a car 3.1 kilometres, or using a laptop for 42 hrs.

Product or activity	Amount equalling 1kg CO_2e
Travelling by car (average occupancy of 1.6 people)	3.1 km
Cotton t-shirt	62% of a shirt
Toilet paper (FSC)	6.4 rolls
Recycled paper (80g/m2)	270 sheets of A4
Coffee	24 cups
Beer	1.6 litres
Using a laptop	42 hours
Average time it takes a person to cause 1kg of CO_2e	42 minutes

Table 2. The significance of 1kg CO_2e. Adapted from Carbotech (2022).

2.3 Principal Sources of Emissions

Greenhouse gas emissions from businesses are typically measured and recorded under three different categories or ‘Scopes’.

Scope 1 Emissions

These emissions are directly generated by the business.

An oyster farms’ Scope 1 emissions may include the use of unleaded fuel, diesel and LPG in work vessels, vehicles, forklifts and generators. Refrigerant used in cool rooms may also be a source of greenhouse gas emissions; however, refrigerants are typically contained in a closed system and only become a source when losses or leaks occur.

Scope 2 Emissions

These emissions are indirectly generated outside of the business but used to provide energy.

An oyster farms’ Scope 2 emissions may include the purchase of grid power supplied to a work shed, enabling the use of lights, graders, washers, baggers, cool rooms, fridges etc.

Scope 3 Emissions

These are indirect upstream and downstream emissions.

- Upstream emissions are emissions produced prior to materials and stock arriving at the farm. This may include the fuel and energy used by hatcheries and nurseries to produce algae and rear spat before these are sent to farms for on-growing. It may also include consumables and materials used on the farm, such as baskets, bags, trays and poles.
- Downstream emissions are emissions produced in the distribution and storage of stock after it has left the farm. This may include fuel and refrigerants used to transport product to market.

2.3.1 Scope 1 Emissions: Fuel Use

Oyster farming relies on vessels equipped with outboard engines that typically run on unleaded petrol. These engines enable farmers to transport stock and cultivation equipment to and from their water-based leases. In some estuary systems, the distance between a farmer's launch site and their lease area can be substantial. For example, a farmer based at Karuah in Port Stephens, may travel over 30km in a round-trip to visit leases at Corrie Island.

While most oyster farmers in NSW have waterfront shed sites, there are locations where these are not available. In such cases, farmers must trailer their work vessels and deploy them at boat ramps every time they need to access their lease area. Towing trailered vessels is another source of fuel use.

Forklifts and other types of loaders are commonly used in oyster sheds across Australia. They facilitate the bulk handling of stock and equipment, reduce manual labour and enhance the efficiency of farming operations. Although unleaded and electric forklifts are available, oyster farmers tend to prefer those powered by either diesel or Liquefied Petroleum Gas (LPG). Generally, LPG engines burn fuel more completely, leading to fewer emissions and less wasted fuel. On the other hand, diesel forklifts tend to produce more torque (i.e. force) and offer greater durability.

2.3.2 Scope 2 Emissions: Purchased Electricity

Commercial oyster cultivation requires not only water-based infrastructure but also a functional land base that typically relies on electricity to power machinery. Oysters are handled regularly during their cultivation, and a variety of machinery may be used at different times to help maintain oyster health, increase farm productivity, and to help ready the stock for sale. Some examples of machinery used include:

<u>Oyster graders</u>: Machines used to efficiently sort, and grade oysters based on various criteria such as size, shape, and weight.

<u>Washers</u>: Machines used to clean oysters by removing dirt, debris, and other impurities from oyster shells prior to sale.

<u>Wet Storage</u>: Wet storage tanks may be used keep oysters alive and 'fresh' long after they're harvested. In some cases, these tanks are chilled and used to provide market opportunities when stock cannot be harvested from the open water.

Other machinery may include baggers, shell grinders, slat strippers, cool rooms and conveyors. All this equipment, as well as lighting, fridges and more traditional shed tools require power, which is typically provided through the grid.

Except for running wet storage tanks and cool rooms, oyster shed activities are principally conducted during daylight hours, and the widespread availability of solar photovoltaic (PV) systems offers farmers the opportunity to reduce their reliance on grid power. A growing number of farms are installing solar systems, and reaping the benefits of lower utility bills, and a reduction in Scope 2 greenhouse gas emissions.

There are also several oyster farms in more remote locations in NSW who have taken this a step further and operate 'off-grid' using battery storage. This allows farmers to operate equipment when the panels are not generating enough electricity (such as at night, or when it's cloudy). Continuous advancements in battery technology and manufacturing processes have led to a dramatic drop in battery costs, making solar plus storage systems increasingly affordable.

In recent years, Australian and State Governments have introduced a range of financial incentives to encourage businesses to invest in solar. Notable programs include the Small-scale Renewable Energy Scheme (SRES) and the Cheaper Home Batteries Program. The SRES currently provides subsidies for both residential and commercial rooftop solar installations, while the Cheaper Home Batteries Program, launching on 1st July 2025, will offer an upfront discount of approximately 30% on the installation costs of eligible battery storage systems.

It should be recognised that the installation of solar systems and battery storage not only reduces greenhouse gas emissions, but also significantly strengthens the industry's ability to manage risk. Access to a reliable power source during severe weather events, when mains electricity may be disrupted, is essential for ensuring workplace health and safety and may be critical to safeguard oyster health.

2.3.3 Scope 3 Upstream Emissions: Growing Infrastructure & Hatcheries

Upstream Scope 3 emissions refer to the greenhouse gases generated during the production of materials utilised on farms. Two of the more notable sources of upstream emissions relate to the manufacture of farming infrastructure, and the production of juvenile stock in hatcheries.

<u>Farming Infrastructure</u> - Items such as oyster baskets, bags, trays, and lines - commonly made from High Density Polyethylene (HDPE) or Polypropylene (PP), have a useable life of 10 to 20 years (OceanWatch Australia 2024). Due to this long lifespan, the emissions associated with

the manufacture of equipment, when apportioned to yearly carbon accounts, would be minimal.

This is highlighted in a life-cycle assessment of live Pacific oysters in NZ, which calculated that the emissions associated with the manufacture of farming infrastructure contributed 1.6% of total emissions (Thinkstep ANZ 2021). It is also supported in the Public Disclosure Statements associated with the Climate Active Certification issued to Harvest Road, an oyster company based in Western Australia. In their published 2022/23 carbon accounts, cultivation infrastructure such as ropes, floats and baskets, accounted for 1.1% of their yearly emissions (Harvest Road 2023).

Shellfish Hatcheries - Upstream emissions may also result from the energy consumed in hatcheries and nurseries to produce juvenile stock. Shellfish hatcheries (in particular) rely heavily on energy to sustain optimal breeding and rearing conditions. This includes maintaining algae cultures, filtering water, operating lighting and pumps, as well as performing critical cleaning and husbandry tasks.

According to research conducted in China (Sun et al. 2021), hatchery activities contribute approximately 62% of the total carbon footprint in the Chinese Pacific oyster industry, when assessed from cradle-to-gate. This industry is heavily reliant on hatcheries to produce triploid Pacific oyster spat for farmers to grow out on their farms.

The situation in New South Wales in relation to seed supply is notably different. The local industry predominantly farms Sydney rock oysters, whose larvae can be naturally collected from the wild. Hatchery production for this species accounts for around 25-30% of cultivated stock (Select Oyster Company 2017, NSW Farmers Association 2025). Furthermore, batches of oysters from hatcheries are distributed across multiple growers, meaning that carbon emissions would be attributed to numerous growers on a pro-rata basis if included in the Scope of a carbon audit. Hatchery operators are also very mindful of their energy consumption and are continuously exploring opportunities to improve energy efficiency.

2.3.4 Scope 3 Downstream Emissions: Transport

Only about 2% of oysters produced are sold directly from farms to consumers, with most market stock distributed to processors and wholesalers in urban areas (Schrobback & Rolfe 2020). Oyster farming takes place across 30 estuaries along the coast of NSW, where farmers typically palletise bags of oysters and use transport companies including Slade, Hines, and East Coast Express to deliver their stock to market.

To meet food safety requirements, oysters must be kept at controlled temperatures post-harvest. Transport companies usually operate large, refrigerated trucks (~22 tonnes), making multiple pick-ups and drop-offs of perishable goods along their routes. While the diesel consumption of these large, refrigerated trucks may be significant, only a portion of the greenhouse gas emissions can be attributed to the transport of oysters, as these trucks carry various goods concurrently.

A useful tool for industry is the CarbonCare CO_2 calculator (www.carboncare.org/en/co2-emissions-calculator), which can provide an estimate of CO_2e emissions based on the shipment weight, and the distance to market. The calculator has been developed in accordance with ISO standard 14083:2023 (Greenhouse Gases – Quantification and reporting of greenhouse gas emissions arising from transport chain operations) and assumes that the truck is running at 80% load capacity.

3 Carbon Opportunities for the NSW Oyster Industry

3.1 Australian Carbon Credit Units (ACCU)

www.cer.gov.au/schemes/australian-carbon-credit-unit-scheme

The Australian Carbon Credit Unit (ACCU) Scheme is a crucial part of Australia's carbon market. It encourages projects that reduce emissions or store carbon, such as reforestation, energy efficiency improvements, and changes in agricultural practices. Participants in the ACCU Scheme can earn one ACCU for every tonne of carbon dioxide equivalent (t CO_2e) emissions their project avoids or stores.

These ACCU's can be sold to the Australian Government through a 'carbon abatement contract' where they are auctioned to those wanting to offset their carbon emissions.

In Australia, businesses that emit more than 100,000 tonnes of CO_2e per year through their Scope1 emissions are required to work with the Australian Governments Clean Energy Regulator and keep their emissions to baseline levels (i.e. regulated limits). This mandatory engagement is known as the Safeguard Mechanism and applies to around 140 businesses that account for approximately half of Australia's emissions.

The baseline levels decrease by approximately 5% each year, compelling businesses to continually reduce emissions. When direct emission reductions are not feasible, businesses may purchase offsets in the form of Australian Carbon Credit Units (ACCU's). Purchasing ACCU's therefore helps businesses lower their reported net emissions. The demand for ACCU's determines their price, which was ~$34 per ACCU in March 2025.

Figure 2. Spot price of Australian Carbon Credit Units (Core Markets 2025).

As explained in section 2.1, there is limited evidence that oysters sequester CO_2. Consequently, the idea that farmers could receive financial compensation for carbon sequestration through initiatives such as the Australian Carbon Credit Unit (ACCU) Scheme lacks support.

The ACCU Scheme does however provide an affordable option for growers to offset any net carbon emissions generated through their farming operations.

3.2 CLIMATE ACTIVE CERTIFICATION

www.climateactive.org.au

An entity attains carbon neutrality by minimising its carbon emissions wherever feasible and offsetting any residual emissions through investments in carbon offset projects, ultimately achieving net zero emissions.

Industries not required to lower emissions under the Safeguard Mechanism can voluntarily pursue carbon neutral certification through the Climate Active Certification program. This certification is administered by the Australian Government's Department of Industry, Science, Energy and Resources.

To be certified under Climate Active, an entity must adhere to the Climate Active Carbon Neutral Standard, which broadly involves four key steps:

1) Calculate emissions,
2) Reduce emissions where possible,
3) Offset / Purchase remaining emissions, and
4) Publicly reporting on achievements.

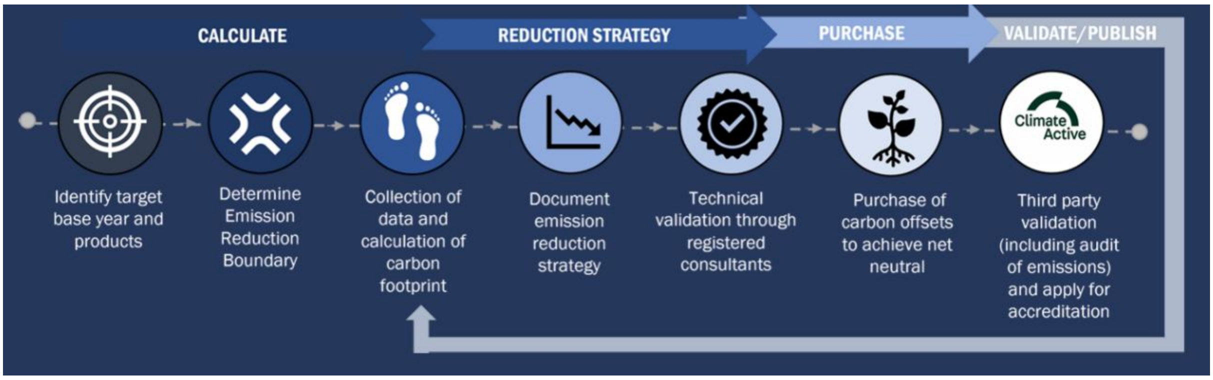

Figure 3. The steps involved in Climate Active Certification (Nine-Squared 2022).

Any business can self-evaluate their activities against the Climate Active Carbon Neutral Standard. However, only those entities that fulfill the certification requirements and enter into a Licence Agreement are authorised to claim Climate Active certification and use the trademark.

3.2.1 Emissions Boundary

The first step towards assessing the carbon footprint of a business is to determine the emissions boundary. This refers to the scope of activities and sources of greenhouse gas emissions that will be included in the carbon account.

Mapping both upstream and downstream process emissions can assist in determining the emission boundary, and as a rule, all services, materials and energy flows that become the product, make the product and carry the products through its life should be included. These elements are called 'attributed processes.'

All attributed processes must be included in the emissions boundary of the product unless they fulfil all the conditions for exclusion, which are:

- A data gap exists, and cannot be collected (i.e. no actual data)
- Extrapolated or proxy data cannot be derived to fill the gap (i.e. no projected data)
- The emissions generated by this process are expected to be negligible, contributing less than 1% to the overall carbon footprint.

An example of an emissions boundary is shown below in Figure 4.

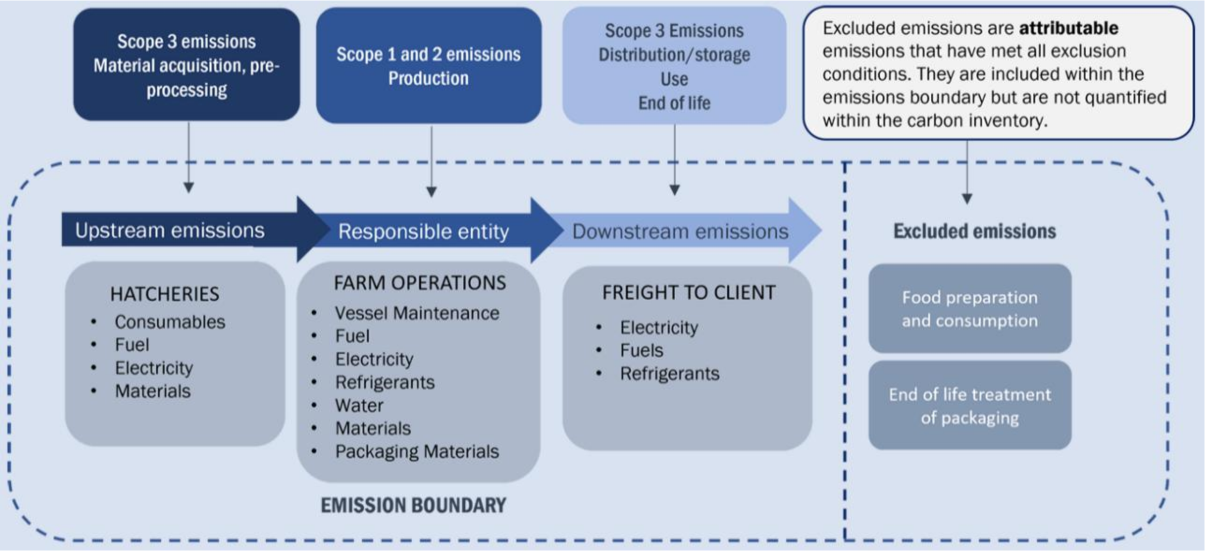

Figure 4. An example of an emission boundary, and emission sources attributed to upstream and downstream components of the supply chain and operations (Nine-Squared 2022).

To help businesses calculate their emissions, the Australian Government has published the Australian National Greenhouse Accounts Factors (2024) which provide standard emission values to cover various activities, such as fuel consumption, electricity use, and waste management. This offers Australian businesses a consistent way to estimate their emissions.

The FRDC will also shortly be launching an Aquaculture Carbon Emissions Calculator. Once live, the calculator will be available as an online tool hosted on the Environmental Accounting Platform managed by Agricultural Innovation Australia (AIA).

Figure 5. Landing page of AIA's Environmental Accounting Platform

The principal sources of emissions for oyster farms are discussed in section 2.3 and includes the burning of fuel, electricity use, upstream emissions from hatcheries and gear manufacturers, and downstream emissions associated with transport of stock to market. Whilst some of this information is relatively simple to collect, calculating the energy required to farm oysters through their life cycle, with a high degree of accuracy, can be complex, and may require external expertise in life cycle assessment.

3.3 Life Cycle Assessments (LCA) & Carbon Footprinting

Life Cycle Assessment (LCA) is a framework for evaluating resource use, emissions, and the environmental impact of a product throughout its entire life cycle. The principals and guidelines for conducting LCA's are outlined in the International Standard ISO 14044:2006, ensuring consistency, transparency, and scientific rigor in environmental assessments.

Carbon footprinting is a subset of LCA, focuses specifically on quantifying greenhouse gas emissions associated with a product. ISO 14064 and 14067 provide internationally recognised methodologies for measuring, reporting, and verifying carbon footprints. ISO 14064 establishes requirements for organisational-level GHG accounting, while ISO 14067 defines product carbon footprinting methodologies. These standards enable businesses to assess emissions, set reduction targets, and participate in carbon markets or offset programs.

For an oyster farm, carbon footprint assessments are typically conducted on a 'Cradle-to-Gate' basis, which examines all emissions from material acquisition up to the point when the product leaves the farm gate. While some assessments may adopt a 'Cradle-to-Grave' approach, tracking the product through to its end-of-life disposal, this method is generally not suitable for oyster farms, because farmers usually lose traceability of their product once it is sent to processors or wholesalers.

3.4 Science Based Targets Initiative (SBTi)

www.sciencebasedtargets.org

An alternative to carbon neutral certification (such as Climate Active), is the Science Based Targets Initiative (SBTi). The SBTi is a global organisation established in 2015 to help businesses set emissions reduction targets that are aligned with climate science. The main difference between the SBTi and carbon neutral certification is that the SBTi focuses on businesses taking meaningful action to limit global warming to below 1.5°C, in line with the Paris Agreement, whereas carbon neutral certification primarily focuses on balancing emissions through offsetting.

Businesses looking to align with the Science Based Targets initiative (SBTi) follow a structured approach to setting and achieving emissions reduction goals.

1. Commitment & Strategy Development
   Businesses start by publicly committing to science-based targets, signalling their dedication to climate action. They then assess their current emissions footprint across Scope 1, 2, and 3 emissions (direct, indirect, and supply chain emissions) and develop a strategy to reduce them.

2. Setting Targets & Validation
   Businesses set short-term and long-term targets based on SBTi's criteria. These targets must align with the Paris Agreement's goal of limiting global warming to below 1.5°C. SBTi reviews and validates these targets to ensure they meet scientific standards.

3. Implementation & Emissions Reduction
   Businesses implement energy efficiency measures, transition to renewable energy, optimise supply chains, and invest in low-carbon technologies. The focus is on real emissions reductions, rather than relying on carbon offsets.

4. Monitoring & Reporting
   Businesses track their progress using GHG accounting frameworks and report their emissions reductions transparently. Many businesses integrate science-based targets, or SBTs, into their sustainability reports to demonstrate accountability.

Businesses that successfully set and have their targets validated by the SBTi are said to have "science-based targets", not that they are "SBTi certified". The cost to have science-based targets validated for Small and Medium Enterprises (SME's) is ~$2,000 AUD.

It should be recognised that the SBTi, and science-based targets in general, are also not without their criticisms. Reisinger et. al (2024) for example, contests that science-based targets oversimplify complex scientific findings and lead to inequitable emissions reduction efforts.

4 CARBON ASSESSMENTS: INDIVIDUAL FARMS

4.1 OVERVIEW OF PROCESS

In 2024, NSW Farmers partnered with Blueshift Consulting, a firm specialising in 'blue carbon,' to develop a carbon audit tool. Blueshift has a track record of analysing energy use and carbon emissions in the Australian aquaculture sector, having created self-assessment tools through a 2020 Fisheries Research Development Corporation project (Blueshift Consulting 2022). These tools were adjusted for the NSW oyster industry, with twenty-four farms stepping forward to participate. Some of these farms requested multi-year audits, allowing them to compare emissions over time. This helped to reveal the impact of changes in farming practice and production volume. In total, thirty-one audits were undertaken.

Most farm assessments were conducted through face-to-face interviews, with a few undertaken remotely. Since the assessments were not intended for formal certification, the data provided by farmers was assumed to be truthful and accurate to the best of their knowledge. If evidence to validate the data could be provided this was helpful, but not mandatory.

4.2 EMISSIONS BOUNDARY

The project did not have the resources to enable full life cycle assessments of individual farms; however, the emissions boundary was considered to include the primary sources of potential greenhouse gas emissions (Box 2).

Box 2. Notable inclusions and exclusions in the emissions boundary.

Inclusions

- Unleaded fuel
- Diesel
- LPG
- Refrigerant use
- Electricity purchased
- Transport to market (to 1st receiver)

Notable exclusions

- Energy use in hatcheries
- Material / gear production
- Consumables
- Vessel maintenance

The exclusions primarily relate to upstream Scope 3 emissions, meaning the emissions boundary extends from the farmgate → first receiver. While proxies and international examples could be utilised to estimate these figures, and potentially enhance the accuracy of the assessments, emissions from these sources are considered relatively minor for the reasons detailed in section 2.3.3. Therefore, for this study, achieving this level of accuracy was not deemed essential.

4.3 Farm Reports

Farmers participating in the project were provided with individual farm reports, an example of which is provided below.

Carbon, Nitrogen & Phosphorus Assessment
ABC Oyster Farm: 2022-23 FY

CARBON EMISSIONS

Table 1. Emissions profile

Emission Type	Scope	Annual Emissions (kg CO_2e)
Fuel: Unleaded	1	5,288
Fuel: Diesel	1	3,027
Fuel: LPG	1	900
Electricity	2	2,765
Transport to 1st receiver: Farm → Sydney	3	227
TOTAL EMISSIONS		**12,207 kg CO_2e**
TOTAL EMISSIONS PER KG OF HARVESTED PRODUCT Based on oyster harvest of 10,389 kg (17,696 dz).		1.17 kg Co_2e / kg of product

Figure 1. Emissions breakdown by source

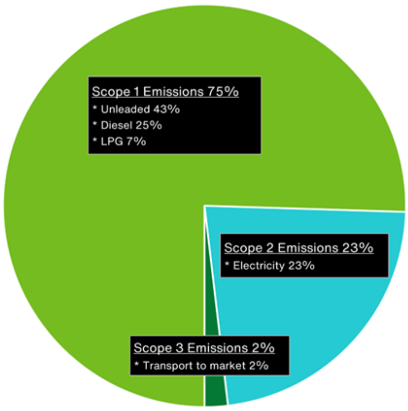

Table 2. Comparison to other marine proteins

Other Marine Protein	Emissions CO_2e per kg of product
ABC Oyster Farm	**1.17**
Wild-caught sardines	1.60
Wild-caught prawns	6.70
Farmed salmonids	8.50
Australian farmed prawns	9.68
Rock lobster	11.20
Imported farmed prawns	12 to 14
Farmed barramundi	13.50
Farmed tuna	17.90

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Oyster shell as a carbon sink

Oyster shells are composed ~92% calcium carbonate ($CaCO_3$), however oyster shells are not recognised as a carbon sink. The formation of shell is actually a potentially net source of carbon dioxide (CO_2). This is because under most growth conditions, oysters release marginally more CO_2 through the calcification process and through respiration than they ultimately store (Han, et al., 2017[1]).

Net emissions & indicative offset cost

- Net emissions of 12.21 tonnes CO_2e
- One Australian Carbon Credit Unit (ACCU) represents one tonne of carbon dioxide equivalent (CO_2e)
- Using a Feb 2025 spot price of $34 per ACCU, annual emissions of 12.21 t CO_2e, could be offset for approximately $415.

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NSW FARMERS

OPTIONS TO DECREASE EMISSIONS

- 75% of business emissions arise from fuel burnt on the farm.
- Consider fuel efficiency when upgrading engines, and stay informed about advancements in electric outboards and battery technology.
- Plan punt use to minimise the number of trips required, and maintain punts and outboards in optimal condition to ensure efficient operation.
- Consider installation of a solar system. 1kW solar panels produce ~4kWh/day. You use ~10 kWh/day, so just a small solar system should suffice if you are considering this to power daytime shed operations.

NUTRIENT REMOVAL

Nutrient removal calculation[2] is based on the nutritional composition of oyster meat and shell, and the weight of stock harvested. The valuation of this service follows Australia's Reef Credit Scheme pricing framework. Although subject to market fluctuations, 1 kg of nutrient removal has previously been valued at $100.

Table 3. Nutrient removal & indicative value of service

	Nitrogen	Phosphorus
Mass removed (kg)	58.0 kg	7.2 kg
Value of nutrient removal service ($)	$5,800	$720

Table 4. Key data provided for assessment

Field	Data	Additional Information
SRO harvested – Small SRO harvested – Medium SRO harvested – Large	1,800 dz 7,151 dz 8,745 dz	Weight of stock estimated as 10,389 kg. 100% own wild-caught stock.
Fuel used	1,823 litres of unleaded 894 litres of diesel 423 litres LPG	Based on $3,600 expense. Based on $1,820 expense. 12 x 18kg tanks x 1.96 to L
Electricity used	3,500 kWh	Grid. Based on $1,500 expense.
Transport to 1st receiver: Farm ➔ Sydney	8,867 kg cargo weight 400 km	Stock weight (8,237kg) + 18 pallets. 18 shipments
Local deliveries	2,152 kg cargo weight	2,152 kg delivered locally. Fuel use accounted for above.

Please note that due to lack of data, this assessment does not attribute any emissions from hatcheries or nurseries used to produce spat, or emissions released in the manufacturer of equipment used on farm. These emissions would be included in a certified assessment.

References

1. Han T, R. Shi, Z. Qi, H. Hunag and H. Liu. 2017. *Interactive effects of oyster and seaweed on seawater dissolved inorganic carbon systems: implications for integrated multi-trophic aquaculture.* Aquaculture Environment Interactions, 469-478.

2.

	SRO	PO
kg TN / t of oysters harvested	5.58	4.46
kg TP / t of oysters harvested	0.69	0.55

More details on this methodology will be provided in the 'NSW Report' published on the NSW Farmers website in 2025.

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This project was funded by the Australian and NSW Governments Storm & Flood Industry Recovery Program.

NSW GOVERNMENT

Australian Government

It is worth noting that in the seafood sector, emissions are often reported in kg of CO_2 equivalent per kilogram of product harvested. The oyster industry usually works in dozens rather than kilograms. Where farmers were unable to provide accurate estimates of whole oyster weights, the following figures were used to enable conversion.

Species and size/grade	Individual oyster weight (g)	Weight per dozen (kg)
Large Sydney Rock Oysters (>70mm length)	55	0.66
Medium Sydney Rock Oysters (55-70mm length)	40	0.48
Small Sydney Rock Oysters (<55mm length)	30	0.36
Large Pacific Oysters (>85mm length)	95	1.14
Medium Pacific Oysters (70-85mm length)	75	0.90
Small Pacific Oysters (<70mm length)	55	0.66

Table 3. Estimating oyster weights in the absence of accurate weight-based data.

The oyster grades presented in the left column of Table 3 follow the grading system used by NSW DPIRD in their annual production reports. However, the weights quoted by NSW DPIRD for Pacific oysters were deemed to be inaccurate and were recalculated during this study. This recalculation was based on the average weights reported by Pacific oyster growers (both diploid and triploid) and independent measurements conducted during the study. It should be noted that the figures provided in Table 3 now align more closely with the Australian Fisheries and Aquaculture Statistics reports published by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), who work on the basis that one dozen Pacific oysters weigh 1kg.

5 Carbon Assessment: State-Wide Extrapolation

5.1 Overview of Process

Although thirty-one individual farm assessments were undertaken, six these were not considered to be representative of a typical NSW oyster farm.

- Two farms were excluded as they are significant oyster nurseries. Their harvest of mature stock for the market was also heavily impacted by disease in the year assessed.
- Two farms were excluded as these operate significant retail premises from their land-based depot sites.
- One farm was excluded as they are a significant distributor of oysters for other farmers and maintain multiple chilled wet storage facilities on site to support this activity.
- One farm was excluded as they used the assessment process to model an ideal production scenario. This farm forecast the sale of stock at certain grades, estimated electricity and fuel use, as well as their supply chains to preferred markets.

The electricity purchased by the first five businesses listed above were elevated due to their operating model. Although these businesses are a legitimate part of the NSW oyster industry, they are not thought to be representative of a 'typical' oyster farm.

Box 3. Effect of including all farms.

Including these six farms would increase the carbon footprint estimate calculated in this report by 11%, with their unique operation models distorting the industry average. On this basis, the figures presented in this report may underestimate industry emissions. Conversely, in the 22/23 FY, farmers were still rebuilding following natural disasters, resulting in a lower oyster harvest compared to six of the previous seven production years. This would result in elevated farm emissions per kg of product, meaning the reported figures could also be considered an overestimate.

The process used to estimate statewide greenhouse gas emissions is summarised below in Figure 6.

1. Consolidate emissions data from individual farms (Appendix 1).

2. Calculate gross emissions per kg of product harvested.

3. Calculate average emissions by source.

4. Extrapolate gross statewide emissions and indicative offset cost.

5. Calculate gross emissions per 100 grams of protein.

Figure 6. The process used to estimate statewide greenhouse gas emissions for the NSW oyster industry.

5.2 Emissions Per Kilogram of Product Harvested

Farm emissions need to be standardised so that they can be compared to other businesses and other products. One common unit of comparison is to establish the CO_2e emissions per kilogram of product harvested.

Farm #	Oysters harvested (dz)	Weight of stock harvested (kg)	Gross emissions (kg CO_2e)	Standardisation (kg CO_2e / kg product)
1	1,066	576	2,231	3.87
2	1,500	1,194	6,592	5.52 (highest)
3	4,750	2,850	10,207	3.58
4	12,100	5,525	25,680	4.65
5	13,830	7,669	13,448	1.75
6	15,120	8,224	6,330	0.77
7	16,559	6,072	16,365	2.70
8	17,696	10,389	12,207	1.17
9	20,700	11,560	16,406	1.42
10	21,000	15,120	15,162	1.00
11	22,272	13,363	35,200	2.63
12	22,850	11,609	13,774	1.19
13	24,660	15,040	9,132	0.61
14	25,898	16,872	16,099	0.95
15	28,164	16,492	7,626	0.46
16	28,245	16,905	15,679	0.93
17	28,977	12,000	3,284	0.27
18	30,000	16,000	15,540	0.97
19	32,000	15,000	28,172	1.88
20	32,908	21,127	15,747	0.75
21	34,598	31,076	13,026	0.42
22	40,000	26,960	9,989	0.37
23	49,630	25,600	2,287	0.09 (lowest)
24	49,891	27,430	23,687	0.86
25	77,917	38,958	14,553	0.37
Total	652,331 dz	373,611 kg	348,423 kg CO2e	**Average = 0.93 CO_2e / kg**

Table 4. Standardising gross emissions from twenty-five NSW oyster farms to calculate emissions per kilogram of product harvested (whole weight).

As shown in Table 4, the observed range of carbon footprints among the farms surveyed was 0.09 - 5.52 kg CO_2e / kg of product harvested. Considering the cumulative emissions across the sample, and cumulative weight of stock harvested, this generates average farm emissions of **0.93 kg CO_2e per kg of product**.

This table also reveals a downward trend in emissions per kilogram as farm production increases (Figure 7). This pattern is not surprising given that all growers must perform a standard set of essential tasks regardless of farm size and output. These activities - including lease maintenance, stock drying, and grading - require the use of fuel and electricity, but do not directly correlate with harvest volume. By pooling harvested product and emissions, this suppresses the impact of those smaller, more inefficient farms on the average.

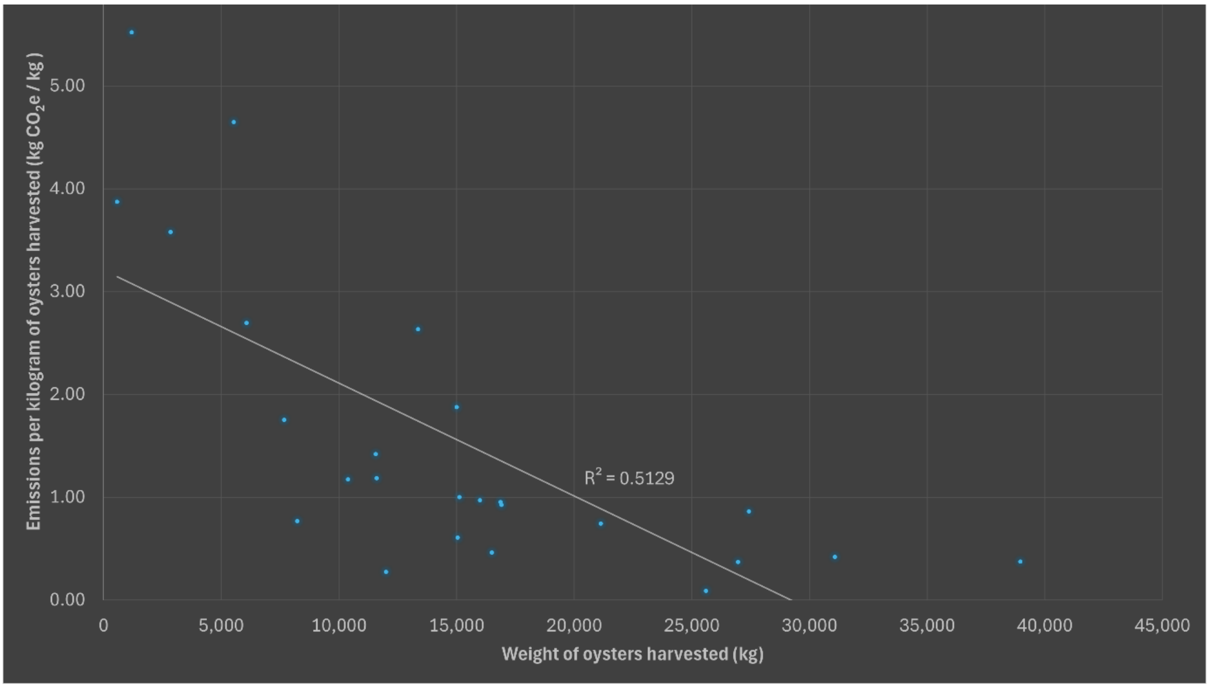

Figure 7. The negative correlation between the volume of oysters harvested in a year, and emissions per kilogram of product.

5.3 Source of Emissions

	Scope 1			Scope 2	Scope 3	Total
	Unleaded	Diesel	LPG	Purchased electricity	3rd party transport to markets	
kg CO_2e per kg of oysters harvested	0.39	0.32	0.02	0.18	0.02	0.93
% of emissions	42%	34%	2%	19%	3%	100%

Table 5. Average greenhouse gas emissions by source.

The table above indicates that over 75% of oyster farm emissions arise from the burning of fuel (predominantly unleaded). While unleaded fuel was used by every farmer in the study to power outboard engines, diesel use was variable. Although most farmers used diesel to some extent in forklifts and work vehicles, the distances travelled (and fuel consumed) varied considerably depending on farm location and operating model. Some growers for example, transport stock between estuaries and even deliver their final product to customers using their own vehicles.

Electricity purchased from the grid made up approximately one-fifth of farm emissions. Despite solar system being utilised by seven of the participating businesses, four of these farms still needed to source energy from the grid. One of these farms needed to purchase a significant amount, suggesting:

- their solar system was undersized for their energy needs,
- their solar system was not operating effectively, and/or
- they required energy during the night when their PV panels were ineffective, e.g. a farm running cool rooms or wet storage tanks require power 24 hours of the day.

The use of third-party transport to move stock to the market accounted for 3% of industry emissions. The NSW oyster industry supplies the domestic market, almost exclusively customers in Sydney, Melbourne, Brisbane and regional NSW. Refrigerated trucks are used to move product to the market, and a very large number of oysters can be transported in a single pallet space. These trucks are highly efficient movers of product along the coast and are simultaneously transporting other goods to market for other vendors.

5.4 Statewide Emissions Estimate

In the 2022/23 production year, the NSW oyster industry reported the harvest of 5,552,904 dozen oysters (NSW DPIRD 2023, Table 6). Using the whole weights provided earlier in Table 3, this equates to an oyster harvest of 2,838,842 kg of product.

	Harvested volume (dz)	Weight per dozen (kg)	Whole oyster weight (kg)
Large SRO	1,087,828	0.66	717,966
Medium SRO	2,504,726	0.48	1,202,268
Small SRO	1,567,112	0.36	564,160
Large PAC	119,423	1.14	136,142
Medium PAC	156,611	0.90	140,950
Small PAC	117,204	0.66	77,355
Total	5,552,904 dz	-	2,838,842 kg

Table 6. Translating oyster harvest data from NSW DPIRD (2023) to whole weights.

Using average farm emissions of 0.93 kg CO_2e per kg of product harvested, this equates to industry wide emissions of **2,640,123 kg CO_2e**.

Box 4. Validating use of 0.93 kg CO_2 / kg of product harvested.

The 2022-23 NSW DPIRD Aquaculture Production Report indicates there were 243 Class-A Aquaculture Permit Holders in the state at the time, of which:

- 44% produced < 5,000 dozen: Classified as small producers.
- 42% produced between 5,001 > 35,000 dozen. Classified as medium producers.
- 14% produced > 35,001 dozen. Classified as large producers.

Calculating the average emissions for each of these production categories from Table 4 provides the following information:

- 106 small-scale producers with average emissions of 6,343 kg CO_2.
- 103 medium-scale producers with average emissions of 15,493 kg CO_2.
- 34 large-scale producers with average emissions of 12,629 kg CO_2.

This approach yields industry wide emissions of 2,697,523 kg CO_2e, which is within 3% of the estimate provided of 2,640,123 kg CO_2e, validating the use of 0.93 kg CO_2e / kg of product.

5.5 Offsetting Statewide Emissions

In the previous section it was calculated that across the 2022/23 financial year, the greenhouse gas emissions from the NSW oyster industry from farmgate-to-first receiver were approximately 2,640,123 kg CO_2e.

Utilising a March 2025 spot price of $34 for one Australian Carbon Credit Unit (i.e. 1t CO_2e), this translates into a **total cost to offset of ~$90,000**. With 243 oyster farmers in the state, this equates to ~$370 per farm, or ~1.5 cents per dozen. As oysters are typically sold by the bag, approximate premiums for these units are provided below in Table 7.

Product	Count	Indicative premium per bag to offset emissions
1 bag x SRO large	50 dz.	$0.81
1 bag x SRO medium	60 dz.	$0.97
1 bag x SRO small	70 dz.	$1.13
1 bag x PAC large	20 dz.	$0.32
1 bag x PAC medium	25 dz.	$0.41
1 bag x PAC small	30 dz.	$0.49

Table 7: The indicative cost to offset greenhouse gas emissions from different oyster products. This assumes a uniform, per dozen premium to offset statewide emissions, irrespective of the production method, species grown or grade harvested.

5.6 Emissions Per 100 Grams of Protein

In section 5.2, average farm emissions were determined to be 0.93 kg CO_2e per kilogram of oysters harvested. While this metric is useful for certain comparisons, a more insightful measure for evaluating greenhouse gas emissions across the agrifood sector, is emissions per 100 grams of protein. This conversion is particularly significant for oysters, given the relatively high shell-to-meat weight ratio.

	Shell - Meat Weight Ratio	Total weight (kg)	Meat weight (kg)	
Large SRO	75.6% - 24.4%	717,966	175,184	SRO total meat weight = 606,192 kg
Medium SRO		1,202,268	293,353	
Small SRO		564,160	137,655	
Large PAC	83.8% - 16.2%	136,142	22,055	PAC total meat weight = 57,421 kg
Medium PAC		140,950	22,834	
Small PAC		77,355	12,532	
Total		2,838,842 kg	663,613 kg	

Table 8. Converting whole oyster weights from the 2022/23 production year into meat weights. Sydney rock oyster (SRO) shell-meat ratio obtained from Nine-Squared (2022). Pacific oyster (PAC) shell-meat ratio obtained from (Hickey 2008).

According to the Australian Food Composition Database, published by Food Standards Australia New Zealand (FSANZ), protein makes up 10.6% of the meat weight of Sydney rock oysters and 10.8% of Pacific oysters. This allows for the calculation of total protein (Table 9).

	Meat weight (kg)	Protein (%)	Weight of protein (kg)
SRO	606,192	10.6%	64,256
PAC	57,421	10.8%	6,201
Combined	658,644 kg		70,457 kg

Table 9. Calculating the weight of protein harvested in NSW oysters across the 2022/23 production year. Oyster composition data sourced from Food Standards Australia New Zealand (FSANZ).

Based on 2022/23 NSW Aquaculture Production Report, the NSW oyster industry emissions can therefore be estimated as **3.75 kg CO_2e per 100g protein**.

5.7 Recalculations Recognising Shell as a CO_2 Sink

Section 2.1 outlined the reasoning for excluding shell carbon from the statewide footprint analysis, citing the argument presented by Pernet et al. (2025). Their analysis highlights that bivalves secrete calcium carbonate shells by utilising carbon from bicarbonate ions, a process that does not result in a short-term reduction of atmospheric CO_2. Consequently, while shell formation may act as a carbon sink, it does not function as a carbon dioxide removal mechanism.

This viewpoint remains a topic of ongoing discussion among scientists, with researchers like Domech et al. (2025) and Feng et al. (2023) acknowledging the carbon stored in shells as a sink in their footprint assessments of bivalve aquaculture. In this section, we reassess the footprint analysis, operating under the assumption that shell formation contributes to CO_2 sequestration.

The Australian National Greenhouse Gas Accounts Factors (Australian Government 2024) outlines a simple but robust method that can be used to estimate CO_2 sequestered in oyster shells. This is based on using the CO_2 emissions from the application of lime ($CaCO_3$), as a proxy for the carbon dioxide sequestered into shells. Emissions from lime are represented by the equation below.

$E = M * P * EF * CtoCO_2$

Where E = CO_2 emissions, M = mass of lime applied, P = purity of lime (i.e. $CaCO_3$ content of lime), EF = default emissions factor for limestone 0.12 (IPCC 2006) and $CtoCO_2$ is the conversion of C to CO_2 (3.67).

If we populate the equation for 1 kg of oyster shells, with a calcium carbonate content of 92%, then:

$E = 1 * 0.92 * 0.12 * 3.67$

Each kg of oyster shell therefore represents 0.4 kg CO_2 from the atmosphere.

Following the shell-to-meat weight ratios presented previously in Table 8, it can be calculated that in the 2022/23 production year, the NSW oyster industry harvested 2,175,228 kg of shell weight (Table 10), equating to **sequestration of 870,091 kg of CO_2.**

	Shell - Meat Weight Ratio	Total weight (kg)	Shell weight (kg)	
Large SRO	75.6% - 24.4%	717,966	542,782	SRO total shell weight = 1,878,202 kg
Medium SRO		1,202,268	908,915	
Small SRO		564,160	426,505	
Large PAC	83.8% - 16.2%	136,142	114,087	PAC total shell weight = 297,026 kg
Medium PAC		140,950	118,116	
Small PAC		77,355	64,823	
Total		2,838,842 kg	2,175,228 kg	

Table 10. Converting whole oyster weights from the 2022/23 production year into shell weights. Sydney rock oyster (SRO) shell-meat ratio obtained from Nine-Squared (2022). Pacific oyster (PAC) shell-meat ratio obtained from (Hickey 2008).

If shell formation were recognised as a carbon dioxide reduction mechanism, oyster farming emissions would decrease by 33%, resulting in a revised total of 1,770,032 kg CO_2e. The comparison between statewide carbon footprint estimates - both excluding and including shell as a CO_2 sink - is summarised in Box 5 below.

Box 5. Comparing statewide carbon footprint estimates depending on the exclusion or inclusion of shell as a sink for carbon dioxide.

	Excl. shell as a CO_2 sink	Incl. shell as a CO_2 sink
Avg. emissions per kg of product	0.93 kg CO_2 / kg oysters	0.62 kg CO_2 / kg oysters
Statewide CO_2e emissions (22/23)	2,640,123 kg CO_2e	1,770,032 kg CO_2e
Emissions per 100g protein	3.75 kg CO_2 / 100g protein	2.53 kg CO_2 / 100g protein

It should be noted that if oyster farmers were to account for shell CO_2 sequestration in their greenhouse gas reporting, then any subsequent downstream dissolution of $CaCO_3$ must be attributed to the entity owning the shells at that time. This means the associated CO_2 emissions should be included in that business's greenhouse gas accounts. Conversely, if the sequestration is not claimed by growers, there is no obligation of the downstream entity to report the emissions from $CaCO_3$ dissolution in their greenhouse gas accounts.

5.8 Discussion & Recommendations

The key data calculated in the previous sections are summarised below.

Box 6. A summary of key statistics from the statewide extrapolation.

- NSW oyster farms emit **0.93 kg CO_2e per kilogram of product harvested**, on average.
- In 2022/23 this extrapolates to **2,640 t CO_2e** across the whole sector.
- For comparison to other agrifoods, this translates to **3.75 kg CO_2e per 100g protein.**

To effectively reduce emissions, the industry should prioritise reducing fuel consumption and reliance on purchased electricity.

As previously noted, oyster sheds are ideal sites for solar panel installation, with peak energy generation aligned closely with peak usage, making this a practical and efficient strategy. The Small-scale Renewable Energy Scheme (SRES) currently offers subsidies for rooftop solar installations, providing farmers with protection against future utility price increases and ensuring an independent power source during extreme events when mains electricity may be unavailable.

As wet-storage systems and cool rooms become more prevalent, overnight power demands will rise. With battery costs continuing to decrease and programs like the Cheaper Home Batteries Program being launched in July 2025, farmers should consider these technologies as viable options for improving energy resilience and reducing overall emissions. A cost-benefit analysis of these technologies may well indicate that they pay for themselves over a relatively short period of time (see Box 7).

Purchased electricity contributed 0.18 kg CO_2e per kilogram of oysters harvested, closely aligning with findings from a recent study on Ireland's Pacific oyster industry. That study calculated that electricity for grading, packing, and depuration activities generated 0.20 kg CO_2e per kilogram of oysters (Domech et al., 2025).

Recommendation 1: Farmers should consider leveraging government subsidies and installing solar panels on shed roofs, while also exploring battery storage solutions to meet rising overnight power demands and enhance energy resilience.

Box 7. Return on investment for solar systems

For oyster farms assessed in this study that do not yet have solar systems, annual electricity consumption averaged 3,800 kWh (~10 kWh / day). Based on an average grid electricity price of 36.6 c / kWh (NSW Government 2024), purchasing this electricity would cost ~$1,390 per annum (excluding GST and service charges).

Given that a 1 kW solar system generates ~4 kWh per day in NSW, a 2.5 kW system would be sufficient to meet the average farm's energy needs of ~10kWh / day. While 2.5 kW solar systems are available, most oyster farms who invest in renewable power, opt for greater capacity - typically 6 kW or larger - costing around $6,000 (excl. GST). Under the Australian Small-scale Renewable Energy Scheme (SRES), farmers may be eligible for a rebate of up to 30% on solar installation costs, potentially reducing the upfront expenditure to $4,200. By eliminating the purchase of grid power, this investment could be recovered in approximately three years.

The use of unleaded fuel in outboards was the single largest source of emissions in the assessment. While light-weight electric motors have been available for some time for small recreational vessels, early attempts at larger engines lacked power and range, and relied on heavy batteries. This limited their potential use in commercial applications.

Electric outboard motors have evolved significantly in recent years, driven by advancements in battery technology, motor efficiency, and the growing demand for sustainable solutions (Yachting.com). While the initial outlay for electric outboards might be higher than traditional combustion engines, the long-term savings on fuel and maintenance can be significant. Furthermore, electric motors are generally quieter, making them an attractive option for farmers operating near residential areas.

The market for commercial electric outboards is growing quickly, however the author is unaware of any oyster farmers currently trialling this technology. Integrating electric outboards will require careful assessment of battery weight and placement, potentially requiring modifications to traditional hull - punt design.

The charging of batteries is another key consideration. While standard AC outlets can be used, emerging solar-powered options are beginning to gain traction. SeaVolt, an Australian company, is developing a marine charging network across ports and waterways. By installing charging terminals, they could enable oyster farmers to recharge electric outboard batteries using solar energy from shed-mounted panels.

The oyster industry in Maine (US) is leading the way in electrifying aquaculture operations, with growers already adopting solar panels, lithium batteries, and electric outboards. Driven by both climate concerns and practical benefits - like quieter, cleaner work environments and reduced maintenance - growers are piloting fully electric barges and workboats that process, transport, and refrigerate oysters using renewable energy (Planson 2025). To support this shift, the Island Institute has developed an *Electric Boat Toolkit* tailored to commercial vessels: www.islandinstitute.org/priorities/marine-economy/electric-boat-toolkit

Green hydrogen-powered outboards are also emerging as a potential innovation in marine technology. Unlike conventional combustion engines, hydrogen fuel cells produce zero greenhouse gas emissions, generating only water vapor. Compared to electric outboards, hydrogen would offer extended operational range and rapid refuelling. Leading manufacturers have started to unveil hydrogen-powered prototypes, while Australia's National Hydrogen Strategy aims to position the country as a global leader in green hydrogen production. Government-backed initiatives are also supporting hydrogen adoption, accelerating the transition to cleaner marine propulsion (Australian Energy Council, 2025).

Recommendation 2: Consider proof-of-concept projects to trial electric and hydrogen powered outboards in the oyster industry.

Although the assessments undertaken during this study included the primary sources of emissions associated with the oyster industry; to improve the accuracy of upstream Scope 3 emissions, carbon assessments should ideally be conducted with a selection of commercial shellfish hatcheries and nurseries. A portion of their emissions could then be allocated to grow-out farms based on the volume of stock purchased. Similarly, farms specialising in wild-caught seed could be assessed, with a percentage of their emissions attributed to grow-out farms that acquire juvenile stock from these suppliers.

Recommendation 3: Undertake carbon assessments with oyster hatcheries, nurseries and suppliers of wild-caught spat, so emissions associated with the supply of juvenile animals can be attributed to farms that purchase this stock.

Similarly, there is limited published data on the greenhouse gas emissions linked to the production of equipment and oyster cultivation infrastructure. Given the differing materials used and their varying lifespans, compiling emissions data into a centralised database would enable farmers to accurately allocate these figures in their annual greenhouse gas accounts.

The Australian Lifecycles Database (Aus LCI), managed by the Australian Life Cycle Assessment Society (ALCAS) can provide this function. Once the data is validated and made publicly available through the database, oyster farmers can use this information to evaluate the embodied carbon in farming tools, infrastructure and machinery.

Recommendation 4: Integrate the energy and material inputs of oyster farming infrastructure and machinery into the Australian Lifecycles Database to improve footprint assessments.

As explained in section 2.1, a life-cycle analysis would likely reveal that oysters farmed in the NSW environment would be net emitters of greenhouse gas. While the production of shell releases CO_2, the dissolution (breakdown) of calcium carbonate in seawater will consume it.

Reversible equation: $Ca^{2+} + 2HCO^{-}_{3}\text{-} \rightleftharpoons CaCO_3 + CO_2 + H_20$
Shell biomineralisation: $Ca^{2+} + 2HCO^{-}_{3}\text{-} \rightarrow CaCO_3 + CO_2 + H_20$
Shell dissolution: $CaCO_3 + CO_2 + H_20 \rightarrow Ca^{2+} + 2HCO^{-}_{3}\text{-}$

Pernet *et. al*. (2024) highlights the misconception that harvesting calcium carbonate oyster shell qualifies as a CO_2 sink. He goes on to state that this contradicts the definition of a CO_2 sink, which refers to any process, activity or mechanism that removes CO_2 form the atmosphere. Harvesting oysters removes carbon from the ocean, but this is not the same as removing CO_2 from the atmosphere.

If the oyster industry adopted cradle-to-grave emissions auditing, returning shells back into the water, after meat consumption, could be a way of offsetting the carbon dioxide emitted during shell formation. Opportunities could therefore be explored to collect oyster shells for use in oyster reef restoration work and other in-water purposes. Such use would help offset the emissions released during shell calcification and provide other significant ecosystem services such as erosion control and fish habitat provision.

Recommendation 5: Support research to conduct a life-cycle analysis of oysters, examining carbon flows and their environmental interactions. This will offer a precise evaluation of the species' carbon emissions and sequestration potential.

Recommendation 6: Investigate the potential of returning oyster shells to the ocean following meat consumption, to help offset emissions and support other significant ecosystem services.

Assessed from farmgate-to-first receiver, the NSW oyster industry emissions in 2022/23 were estimated as 2,640,123 kg CO_2e, equating to 0.93 kg CO_2e per kilogram of product harvested.

This can be compared to data for other marine proteins. In 2022 Blueshift Consulting undertook energy use and carbon emissions assessments for various Australian fishing and aquaculture sectors. The data calculated in this report is compared to that generated by Blueshift Consulting in Figure 8 below.

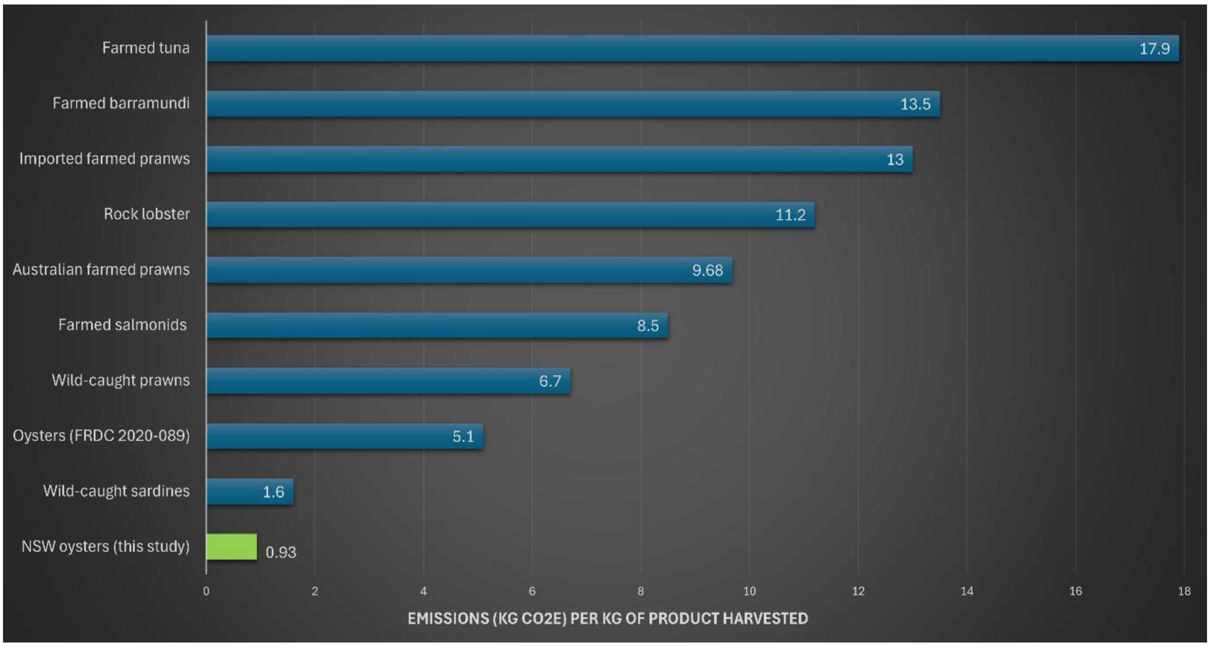

Figure 8. Comparing greenhouse gas emissions per kilogram of product harvested for different Australian marine proteins. Data presented from Blueshift Consulting (2022), and Blueshift Consulting (2024) for updated Australian farmed prawn data. Green = data from this report.

This figure clearly demonstrates that NSW oysters perform well compared to other marine proteins. It is important to note however that the emissions boundary defined by Blueshift (2022) differs slightly from the emissions boundary used in this assessment. Blueshift's calculations included hatchery emissions and third-party processing within the supply chain.

To enable comparison to other agrifoods, emissions data was also standardised against 100g protein, with Figure 9 showing the carbon footprint of a variety of farmed foods. As indicated by Nine-Squared (2022), poultry is typically regarded as a low emissions food source. Using this as a benchmark, foods which produce fewer emissions than poultry are therefore also regarded as having a low carbon footprint.

Emissions of 3.75 kg CO_2e per 100g of protein, aligns with the footprint of live mussels and frozen oysters in New Zealand (Thinkstep 2021). Notably, the same report assessed live oysters from NZ at 5.6 kg CO_2e per 100g protein, highlighting the emissions impact of their export-heavy supply chain. The increased footprint primarily reflects the extended transportation distances required to reach international markets.

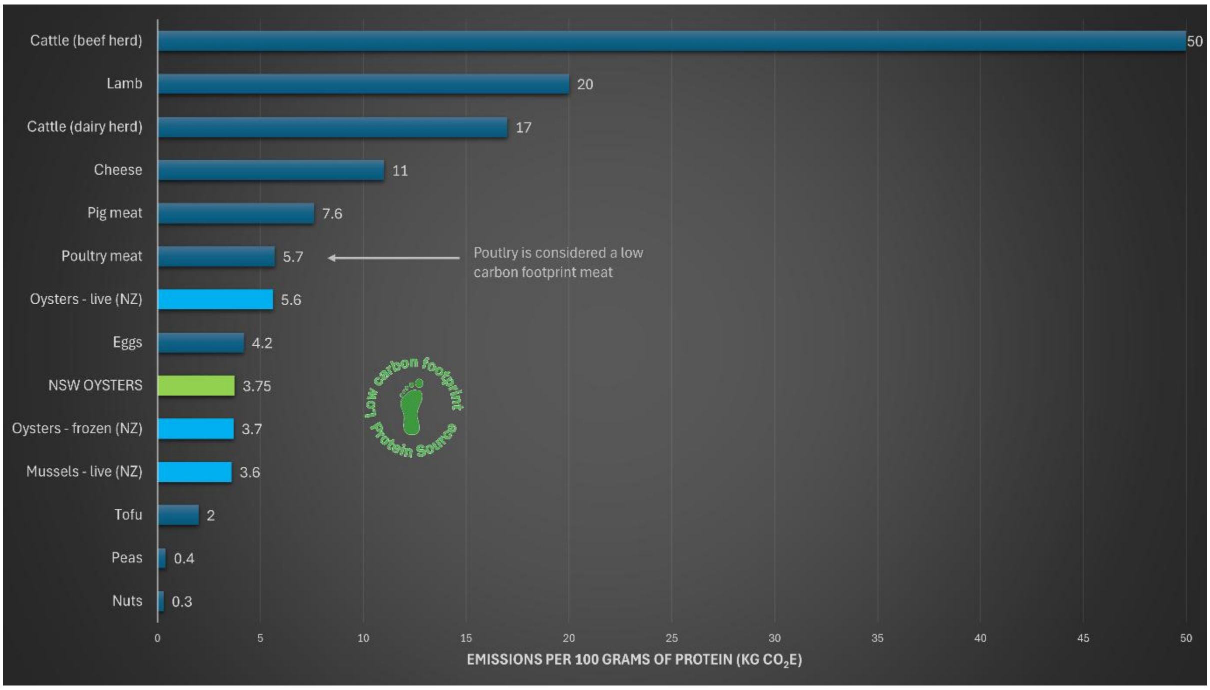

Figure 9. Carbon emissions per 100g of protein across common farmed foods. Data presented in light blue was sourced from ThinkStep (2021), whilst data presented in dark blue/plum was sourced from Poore & Nemecek (2018) as world averages. Green = data from this report.

Overall, the NSW oyster industry operates with an exceptionally low carbon footprint, with the estimated cost to offset emissions < $100,000. If distributed evenly across the sector, this would equate to a cost of ~1.5 cents per dozen oysters sold.

Given the minimal emissions of some businesses, these entities should explore the process of obtaining Carbon Active certification. It would be very insightful to follow a transparent process of certification and document the data gaps required to meet the criteria.

Climate Active certification is typically awarded to individual businesses that meet carbon neutrality requirements. While some sustainability credentials, like the Marine Stewardship Council (MSC) apply across an entire fishery, Climate Active certification does not currently have a standard for industry-wide application without the necessity of individual audits. However, engaging with Climate Active at the sector level could help explore whether a collective approach to certification is feasible.

Recommendation 7: Farmers with minimal emissions should explore third-party certification through Climate Active. A transparent certification process would highlight industry-wide data gaps, facilitating more efficient assessments in the future.

Recommendation 8: Liaise with Climate Active to explore a collective approach to certification.

6 NUTRIENT REMOVAL

6.1 REMOVAL RATES FOR SYDNEY ROCK & PACIFIC OYSTERS

Elemental analysis of Sydney rock oysters (SRO) and Pacific oysters (PAC) has quantified the nitrogen and phosphorus composition of their tissue and shell, as summarised in Table 11.

Component	Sydney rock oysters (SRO)	Pacific oysters (PAC)
Tissue	16.9g N / kg meat	17.4g N / kg meat
	1.83g P / kg meat	1.74g P / kg meat
Shell	1.963g N / kg shell	1.963g N / kg shell
	0.32g P / kg shell	0.32g P / kg shell

Table 11. Nitrogen and phosphorus composition of oyster meat and shell, for both Sydney rock and Pacific oysters. Tissue content data sourced from Food Standards Australia New Zealand (FSANZ), and shell content data from de Roover (2024).

Using the shell-to-meat weight ratios applied earlier in this report, 75.80%-24.20% for Sydney rock oysters and 83.80%-16.20% for Pacific oysters, the meat and shell components can be integrated to determine total nitrogen and phosphorus removal rates.

Component	Sydney rock oysters (SRO)	Pacific oysters (PAC)
Kg TN / t oysters harvested	5.58	4.46
Kg TP / t oysters harvested	0.69	0.55

Table 12. Total nitrogen (TN) and total phosphorus (TP) removal rates.

These rates contrast with those used by BDO in their 2023 assessment of aquaculture's economic contribution to NSW. BDO applied removal rates of 2.3 kg TN and 0.5 kg TP per tonne of harvested oysters, citing van der Schatte Oliver et al. (2018), though the derivation of these figures is not clear.

Using oyster harvest figures from 2022/23 (see Table 6), alongside the nutrient removal rates presented above in Table 12, total nitrogen and phosphorus removal can be estimated as:

- **Total nitrogen removal: 15,444 kg.**
- **Total phosphorus removal: 1,909 kg.**

While shellfish farms will have a larger standing stock, which will cycle nutrients during feeding and excretion, it is the harvested biomass that gives the most certain measure of nutrients removed from the marine system.

The nitrogen and phosphorus content in bivalves can fluctuate based on location, season, species and various environmental factors, though the full extent of these influences is not well documented (Rose et al., 2014, Domech et al., 2025). Additionally, nutrient composition may vary with age, as older oysters tend to develop thicker, proportionally heavier shells.

6.2 Valuing Nutrient Removal

To establish a realistic valuation of nutrient removal, this report references the Reef Credit Scheme (RCS) in Queensland - an innovative market-based approach aimed at improving water quality in the Great Barrier Reef.

The RCS operates similarly to carbon credits, enabling farmers and landholders to earn tradable credits by implementing land management practices that reduce nutrient and sediment runoff. These credits represent a quantifiable reduction in pollutants, such as dissolved inorganic nitrogen (DIN) and fine sediment, prevented from entering the reef catchment. The scheme is managed by Eco-Markets Australia and is supported by government and private investors, including HSBC and Qantas, who voluntarily purchase reef credits to meet sustainability goals. By incentivising pollution reduction, the Reef Credit Scheme provides financial benefits to landholders while contributing to the long-term health of the reef ecosystem.

The value of 1kg of nutrient removal, particularly dissolved inorganic nitrogen, is determined by its impact on reef health and the cost-effectiveness of mitigation strategies. Under the Reef Credit Scheme, one credit equates to the removal of 1kg of nutrient from entering the reef. Pricing details of Reef Credits are not always publicly available, as they are negotiated between sellers and buyers, however in March 2024, one credit was publicly valued at ~$100 (Eco-Markets 2024). Applying this rate, the service provided by the NSW oyster industry in 2022/23 to remove nutrients, can be valued at **$1.74 million**.

	Mass removed (kg)	Value of nutrient removal at $100 / kg ($)
Nitrogen	15,444	$1,544,376
Phosphorus	1,909	$190,918
Total	17,353	$1,735,294

Table 13. Estimated valuation of the nutrient removal service provided by the NSW oyster industry in 2022/23 based on the published Reef Credit purchase price.

Again, this methodology contrasts with the approach taken by BDO (2023), who benchmarked the value of nutrient removal against the cost of using constructed wetland technologies for the same purpose. This approach placed reliance on a particular methodology of nutrient removal, and there was large variability in cost-effectiveness of this method, with values ranging from $45 and $1,023 / kg total nitrogen removed. BDO ultimately applied an average figure of $507 per kg TN and $853 per kg TP.

While both valuation models are valid, the Reef Credit Scheme pricing may provide a more realistic estimate for industry remuneration if a mechanism can be developed that enables shellfish farmers to monetise the nutrient removal service provided by their stock. The benchmark of $100 per kilogram of nutrient removed also aligns closely with a European study evaluating the ecosystem services of Ireland’s Pacific oyster industry, which estimated the value of 1 kilogram of nitrogen removal at ~€55 (~$97 AUD) (Domech et al., 2025).

The concept of oyster farmers receiving ‘Payments for Ecosystem Services (PES)’ is explored further by Nine-Squared (2022).

6.3 Discussion & Recommendations

Over the past to fifty years, nutrient emissions into coastal waters have surged, leading to declining water quality, eutrophication, and nuisance algal blooms (Maúre et. al 2021). Shellfish aquaculture offers a unique solution to help counteract this pollution. Oysters act as natural filters, removing algae and organic matter from the water while incorporating nitrogen and phosphorus into their tissue and shell, supporting healthier marine ecosystems.

This report, along with previous studies commissioned by the NSW Government (BDO 2023), underscores the nutrient removal potential of oysters - presenting a valuable opportunity for the NSW shellfish industry.

As noted by The Nature Conservancy (2024), both Virginia and Maryland in the U.S. have implemented nutrient trading programs. Through one of these schemes, Blue Oyster Environmental, an oyster company, generates credits through shellfish production, which are then sold to the Baltimore Convention Centre to offset event-related environmental impacts.

There is strong merit in trialling a nutrient trading scheme in NSW utilising commercial shellfish production to offset nutrient discharges from anthropogenic sources. The concept of nutrient removal via shellfish to compensate for terrestrial nutrient outputs has been explored, modelled, and piloted in various locations (Lindahl et al. 2005 & Bricker et al. 2018).

Compared to other nitrogen removal methods and offsets, such as riparian and wetland construction (BDO 2023), oyster farming is a lower-intensity, cost-effective solution that also supports sustainable food production and employment opportunities. Nutrient offsets also potentially offer oyster farmers a revenue stream beyond traditional food production.

As indicated by Nine-Squared (2022), there are already state policies in NSW which enable flexible options for environmental offsets to assist with managing point source pollution (particularly nitrogen). In lieu of an established Nutrient Trading Scheme (or Nitrogen Credit Market) an offset proposal would need to be directly linked to an emission producer, most likely through a partnership arrangement, and assessed by the NSW Environment Protection Authority (NSW EPA).

While the industry would not seek to support point-source nutrient pollution, collaborating with such entities to mitigate the impact of nutrient releases could ultimately improve estuarine health, strengthen stakeholder relationships, and provide oyster growers with a diversified income stream beyond the sale of edible oysters.

Recommendation 9: Collaborate with the NSW EPA and a willing nutrient emitter to trial an offset initiative that reduces nutrient impacts through assimilation in farmed oysters.

7 SUMMARY OF RECOMMENDATIONS

Recommendation 1: Farmers should consider leveraging government subsidies and installing solar panels on shed roofs, while also exploring battery storage solutions to meet rising overnight power demands and enhance energy resilience.

Recommendation 2: Consider proof-of-concept projects to trial electric and hydrogen powered outboards in the oyster industry.

Recommendation 3: Undertake carbon assessments with oyster hatcheries, nurseries and suppliers of wild-caught spat, so emissions associated with the supply of juvenile animals can be attributed to farms that purchase this stock.

Recommendation 4: Integrate the energy and material inputs of oyster farming infrastructure and machinery into the Australian Lifecycles Database to improve footprint assessments.

Recommendation 5: Support research to conduct a life-cycle analysis of oysters, examining carbon flows and their environmental interactions. This will offer a precise evaluation of the species' carbon emissions and sequestration potential.

Recommendation 6: Investigate the potential of returning oyster shells to the ocean following meat consumption, to help offset emissions and support other significant ecosystem services.

Recommendation 7: Farmers with minimal emissions should explore third-party certification through Climate Active. A transparent certification process would highlight data gaps, facilitating more efficient assessments in the future.

Recommendation 8: Liaise with Climate Active to explore a collective approach to certification.

Recommendation 9: Collaborate with the NSW EPA and a willing nutrient emitter to trial an offset initiative that reduces nutrient impacts through assimilation in farmed oysters.

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APPENDIX 1 – EMISSIONS DATA FROM INDIVIDUAL FARMS

Farm #	Volume harvested (dz)	Weight of stock harvested (kg)	Emissions by source (kg CO_2e)					Total emissions (kg (CO_2e)
			Unleaded	Diesel	LPG	Purchased electricity	3rd party transport	
1	1,066	576	2,231	0	0	0	0	2,231
2	1,500	1,194	4,525	0	0	2,054	13	6,592
3	4,750	2,850	1,315	8,183	0	709	0	10,207
4	12,100	5,525	18,023	548	0	7,031	78	25,680
5	13,830	7,669	6,509	0	0	6,939	0	13,448
6	15,120	8,224	696	4,797	600	237	0	6,330
7	16,559	6,072	12,358	2,403	0	1,437	167	16,365
8	17,696	10,389	5,288	3,027	900	2,765	227	12,207
9	20,700	11,560	10,559	3,521	0	1,975	351	16,406
10	21,000	15,120	6,034	6,690	998	1,153	287	15,162
11	22,272	13,363	5,648	27,498	0	2,054	0	35,200
12	22,850	11,609	3,672	2,495	0	7,064	543	13,774
13	24,660	15,040	7,533	813	0	786	0	9,132
14	25,898	16,872	1,323	10,810	374	3,002	590	16,099
15	28,164	16,492	5,976	813	0	837	0	7,626
16	28,245	16,905	2,431	10,062	0	2,581	605	15,679
17	28,977	12,000	3,075	0	0	0	209	3,284
18	30,000	16,000	4,525	1,761	0	6,486	2,768	15,540
29	32,000	15,000	19,824	603	0	7,031	714	28,172
20	32,908	21,127	1,453	11,210	374	1,975	735	15,747
21	34,598	31,076	5,523	2,031	1,188	4,029	255	13,026
22	40,000	26,960	1,741	6,094	0	1,264	890	9,989
23	49,630	25,600	1,044	813	0	0	430	2,287
24	49,891	27,430	9,428	7,029	1,689	5,250	291	23,687
25	77,917	38,958	4,525	8,803	374	277	574	14,553