Pathways and opportunities to reduce the carbon footprint of the Australian prawn farming industry

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ABBREVIATIONS

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ACCU	Australian Carbon Credit Unit
AD	Anaerobic digestor
ADA	Aquaculture Development Area’s
APFA	Australian Prawn Farmers Association
ASC	Aquaculture Stewardship Council
BAP	Best Aquaculture Practices
BlueCAM	The blue carbon accounting model
CE	Carbon Equivalent
CED	Cumulative Energy Demand
CFC	Chlorofluorocarbon
CH_4	Methane
CO2	Carbon Dioxide
CO2-e	Carbon dioxide equivalent
CoOL	Country of Origin Labelling
DiD	Difference-in-difference
DO	Dissolved oxygen
EF	Emission Factor
ERP	Emissions Reduction Plan
ESPPE	Energy Savers Program Plus Extension
F&A	Fishing or Fisheries and Aquaculture
FCR	Feed Conversion Ratio
FRDC	Fisheries Research and Development Corporation
FullCAM	Full Carbon Accounting Model
GHG	Greenhouse Gas(es)
GSA	Global Seafood Alliance
GVP	Gross value of production
GWP	Global Warming Potential
Ha	Hectare
HFC’s	Hydrofluorocarbons
Hp	Horsepower
HRO	Harvest Road Oceans
IMTA	Integrated multi-trophic aquaculture system
kWh	Kilowatt hour
LCA	Life cycle analysis
MAAC	Marginal abatement cost curve
MSC	Marine Stewardship Council
MW	Megawatt
N_2O	Nitrous oxide
NCOS	National Carbon Offset Standard
NGA	National Greenhouse Accounts
NGERS	The National Greenhouse and Energy Reporting Scheme
NGO	Non-Governmental Organisation
NRM	Natural Resource Management
P&E	Plant and equipment

PFC's	Perfluorocarbons
PV	Photovoltaic
QFF	Queensland Farmers Federation
QLD	Queensland
QREZ	Queensland Renewable Energy Zone
R&D	Research & development
RD&E	Research, development and extension
SDG	Sustainable Development Goal
SF_6	Sulphur hexafluoride
SLO	Social license to operate
SME	Small and medium-sized enterprises
UNFCCC	United Nations Framework Convention on Climate Change
WTP	Willingness to pay
WWF	World Wildlife Fund

EXECUTIVE SUMMARY

The Australian prawn farming industry faces multiple commercial and environmental challenges associated with climate change and decarbonisation. The sector must deal with the effects of climate change – directly on farms and in supply chains of both its farming inputs and its products. In addition, it faces the imperative to reduce its own carbon footprint in increasingly competitive protein production, sales, and consumption markets. In a 2021 report, initial estimates indicated that the entire prawn farming sector generated 102 kt CO_2-e, representing about 7% of total emissions from the Australian fisheries and aquaculture (F&A) sectors.[1] Farmed prawns were the second most GHG intensive seafood product with 15.2 kg CO_2-e per kg of prawn produced.

This report provides an updated assessment of the carbon footprint of farmed prawns in Australia, building upon the foundation laid by previous projects (FRDC Project 2020-089), which focused on the overall carbon footprint of the fisheries and aquaculture sector. The six key objectives of this project are:

1. Reporting on the carbon balance of prawn production to benchmark the Australian Prawn Farming industry;
2. Identifying differences between large- and small-scale prawn production/farms;
3. Identifying pathways and opportunities for carbon footprint reduction at both enterprise and industry levels, including exploring carbon sequestration and blue carbon potential;
4. Identifying roadblocks and challenges to reducing the carbon footprint at the enterprise and industry levels;
5. Identifying research priority areas that enable the industry to reduce its carbon footprint; and
6. Reporting on the impact of sustainability and carbon neutrality claims/certification on the marketability of prawns.

This project involves a thorough assessment of prawn farmers carbon outputs to identify key contributors and emission reduction methodologies. The study utilises Blueshift Consulting's carbon calculator tool, drawing data from prawn farmers to calculate CO_2-e (Carbon dioxide equivalent) per kilogram of production and provide an industry-wide weighted average (carbon footprint). Opportunities to reduce the carbon footprint were explored across Scope 1, Scope 2, and Scope 3, including aspects like electricity reduction, feed-related reductions, and technological improvements. The project also identified potential roadblocks, conducted a cost/benefit review for research priorities, and examined opportunities to derive benefits from lowered carbon footprints, emphasising sustainability and marketability considerations.

The study provided an analysis of carbon emissions of the Australian prawn farming industry, categorising them into Scope 1 (fuel, aquatic N_2O and refrigerant), Scope 2 (electricity), and Scope 3 (feed, transport and processing). While revealing a comparatively lower carbon footprint than imported products, the study identifies areas for improvement and the roadblocks for farmers to develop these reductions. The approach suggests targeted strategies, including energy audits and sustainable feed practices, highlighting the need for life cycle analysis and a further push towards carbon reductions. Additionally, blue carbon methods are explored, linking prawn farms to coastal ecosystem conservation and carbon sequestration.

[1] FRDC No 2020/089. Bell, Robert A., Blueshift Consulting 2022, Energy use and carbon emissions assessments in the Australian fishing and aquaculture sectors: Audit, self-assessment, and guidance tools for footprint reduction, Canberra, Australia, (April).

The updated carbon footprint of the Australian prawn farming industry reveals key greenhouse gases (GHG) contributors, expressed as CO_2-e per kilogram of produced prawns:

Table 1 Weighted average GHG emissions from prawn farm responses (kg CO2-e per kg of produced prawns)

Scope 1			Scope 2	Scope 3		Total
Liquid fuels	Refrigerants	Aquatic N2O	Electricity	Feed	Transport	
0.41	1.24	1.30	4.25	2.36	0.12	**9.68**

The primary GHG contributors were purchased electricity, emissions from high-protein feed usage, aquatic N_2O, and refrigerant-related emissions. **The observed carbon footprint among surveyed farms ranged from 8.7 to 12.7kg CO_2-e per kg of produced prawns, with a weighted average of 9.68 kg CO_2-e.** Notably, this average is lower than previous estimates, likely attributed to reductions in Queensland grid emissions (through transitions away from fossil fuels) and submissions from larger, more efficient farms.

Scope 1 emissions (liquid fuel, refrigerant and aquatic N_2O) were estimated at 2.05 - 4.84 kg CO_2-e per kg of produced prawns, with a weighted average of 2.95 CO_2-e per kg. This represents 30.5%. Scope 2 emissions (purchased electricity) were estimated at 3.4 - 7.8 kg CO_2-e per kg of produced prawns with a weighted average of 4.25 kg CO_2-e per kg. This represents 43.9% of a typical Australian prawn farm's carbon footprint. Scope 3 emissions (feed and transport) were estimated at 2.27 - 2.76 kg CO_2-e per kg of produced prawns for Australian farms, with a weighted average of 2.48 kg CO_2-e per kg. This represents 25.6% of a typical Australian prawn farm's carbon footprint.

A number of roadblocks for prawn farmers reducing their carbon footprint were identified. These roadblocks include prioritising carbon emissions over other business objectives, complex carbon accounting perceptions, and uncertain financial benefits present potential issues to farmers. Despite these challenges, the potential for cost-effective emission offsetting emphasises the need for strategic alignment, ongoing research, and collaboration for meaningful reductions in the future.

Opportunities to transition to renewable energy sources, as outlined in QLD's targets, are crucial for reducing the prawn farming industry's greenhouse gas emissions. These stem from exploration of Aquaculture Development Areas (ADAs) and collective renewable power generation as a means for industry-wide emission reduction. However, balancing effectiveness with cost considerations is vital. Standardised carbon footprint reporting metrics and advancements in feed technology offer avenues for informed decision-making and cost reduction. Further mitigation strategies include blue carbon sequestration, reforestation, and anaerobic digesters. Carbon offsetting programs such as the Gold Standard and Carbon Neutral Program provide opportunities for farmers to offset their emissions.

Sustainability and carbon neutrality claims boost the marketability of farmed prawn products, driven by growing consumer demand for responsibly sourced seafood. Certification programs like GSA, BAP and ASC now incorporate energy use and carbon footprints. Advantages include increased consumer demand, price premiums, and improved market access. However, costs for reducing carbon footprints, including technology investments and certification, require careful consideration by individual farmers. Conducting cost-benefit analyses is crucial for farmers to identify the feasibility of each carbon reduction opportunity. Pursuing sustainability offers opportunities for market differentiation, profitability, and long-term resilience, despite associated costs and operational changes.

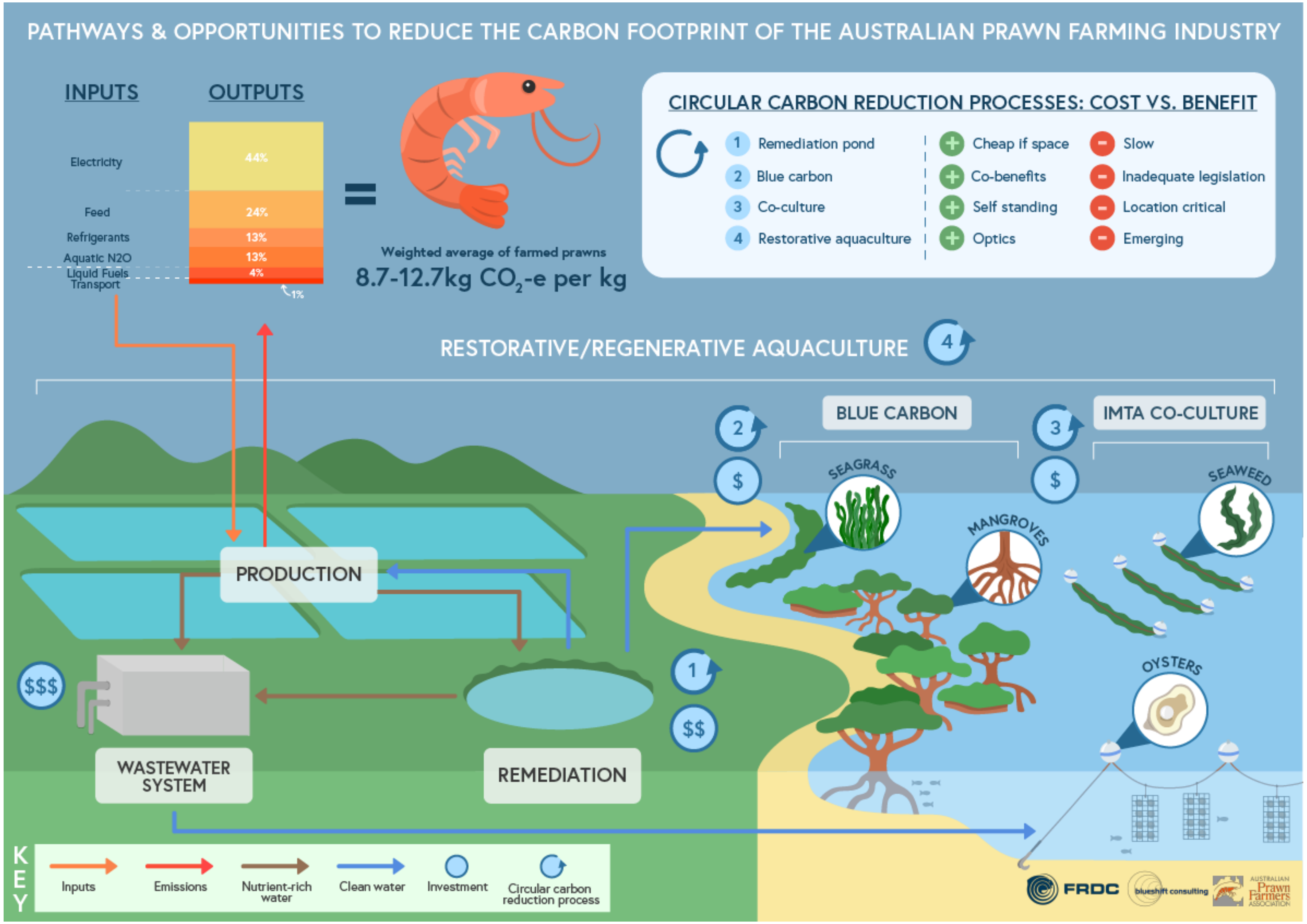

Figure 0-1 Summary of "Pathways and opportunities to reduce the carbon footprint of the Australian prawn farming industry".

1 INTRODUCTION

The Australian prawn farming industry faces multiple commercial and environmental challenges associated with climate change and decarbonisation. The sector must deal with the effects of climate change – directly on farms and in supply chains of both its farming inputs and its products. In addition, it faces the imperative to reduce its own carbon footprint in increasingly competitive protein production, sales and consumption markets. In a 2021 report, initial estimates indicated that the entire prawn farming sector generated 102 kt CO_2-e, representing about 7% of total emissions from the Australian fisheries and aquaculture (F&A) sectors. Farmed prawns were the second most GHG intensive Australian seafood product generating 15.2 kg CO_2-e per kg of prawns produced.[2]

Prawns (or shrimp) are one of the most in demand proteins in the world, with prawn aquaculture growing at a rate of approximately 6% per year. According to the Food and Agriculture Organisation of the United Nations (FAO) shrimp represents about 18% of the value of global seafood trade.

Aquaculture is currently Australia's fastest growing primary industry, accounting for 56% of the total gross value of production (GVP) of seafood with a value of $1.94 billion[3]. From FY18 to FY22, the Australian prawn farming industry grew 126%, from $80m to $181m. The two main species farmed are Black Tiger prawns (*Penaeus monodon*) and Banana prawns (*Penaeus merguiensis*).

As producers of one of the most popular seafood products, the prawn farming industry has the potential to continue to grow sustainability by continuously implementing environmentally responsible practices. A key component for the industry is to identify pathways and opportunities for reducing the carbon footprint of the industry and its consumer facing products.

1.1 Need

Reducing greenhouse gas (GHG) emissions is a primary strategy to mitigating climate change. Australia has committed to a Long-Term Emissions Reduction Plan (ERP) that is a whole-of-economy plan to achieve net zero emissions by 2050[4]. In 2023, Australia made nationally determined commitments under the Paris Agreement that commits Australia to reducing its emissions to 43% below 2005 levels by 2030[5]. These commitments require reductions by defined large organisation GHG producers. In addition to these national commitments, some seafood distributors/retailers have commitments to meet increasing community and consumer expectations.

Best practice environmental performance also has many additional benefits, including funding opportunities. It also provides point of differences, which can offset the costs associated to transition to lower GHG emissions.

A carbon footprint measures the amount of carbon dioxide and other carbon compounds emitted due to human activities, while GHG emissions encompass all gases released into the atmosphere,

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[2] FRDC No 2020/089. Bell, Robert A., Blueshift Consulting 2022, Energy use and carbon emissions assessments in the Australian fishing and aquaculture sectors: Audit, self-assessment, and guidance tools for footprint reduction, Canberra, Australia, (April).

[3] See: www.fao.org/fishery/en/facp/aus

[4] See: https://www.dcceew.gov.au/climate-change/publications/australias-long-term-emissions-reduction-plan

[5] Australia's whole-of-economy Long-Term Emissions Reduction Plan, Australian Government Department of Industry, Science, Energy and Resources (See: www.dcceew.gov.au/climate-change/publications/australias-long-term-emissions-reduction-plan)

contributing to global warming. Both are crucial metrics for understanding and mitigating farmers impact on the environment.

Calculating Australian prawn farmers' carbon footprint will ensure industry alignment with current movements in the food sector to decarbonisation. It will provide guidance in reducing environmental impacts and opening up potential opportunities for benefits of increased industry and brand reputation. To reduce their overall carbon footprint, Australian prawn farmers should investigate opportunities to reduce indirect or direct GHG emissions and consider available carbon offsetting opportunities.

There are several key drivers for calculating further information on carbon footprints and GHG emissions in Australian prawn farming. These include:

- **Establishment of GHG baselines:** Understanding current emissions and stablishing GHG baselines in prawn farming is vital for enabling year to year comparison with other industry benchmarks, complying with regulations, facilitating effective reduction strategies and promoting transparency in environmental impact assessment.
- **Ability to measure, manage and reduce GHG emissions:** Advances in technology, data collection methods and research provide new and improved opportunities to measure, model and analyse GHG emissions.
- **Sustainability goals and certifications:** Demonstration of sustainable aquaculture practices is becoming increasingly important, and certifications such as the ASC Shrimp Standard. ASC requires records of cumulative energy use (CED), which includes energy consumption type (diesel, gasoline, natural gas, electricity, etc) and quantities, energy consumption activities (water aeration, water pumping, office power, internal transportation, etc). See https://asc-aqua.org/wp-content/uploads/2023/07/ASC-Shrimp-V1.2.1-Audit-Manual.xlsx
- **Supply chain accountability:** Several stakeholders within the seafood supply chain, including retailers (e.g., Coles), are increasingly interested in understanding the carbon footprints of products they sell.

1.2 Objectives

This project provides an updated overview of the carbon footprint of Australian farmed prawns and extensively builds on a previous project funded by the FRDC, which provided an overall carbon footprint of the F&A sector[6].

Specifically, the project had six key objectives:

1. Report on the carbon balance of prawn production – benchmark the Australian Prawn Farming industry;
2. Identify any differences between large- and small-scale prawn production/farms;
3. Identify pathways and opportunities to reduce carbon footprint – enterprise and industry level (including carbon sequestration and blue carbon potential);
4. Identify roadblocks and challenges to reduce carbon footprint – enterprise and industry level.
5. Identify research priority areas to enable industry to reduce its carbon footprint; and
6. Report on the impact of sustainability and carbon neutrality claims/certification on prawn marketability.

[6] FRDC No 2020/089. Bell, Robert A., Blueshift Consulting 2022, Energy use and carbon emissions assessments in the Australian fishing and aquaculture sectors: Audit, self-assessment, and guidance tools for footprint reduction, Canberra, Australia, (April).

1.3 Overview of the Australian prawn farming industry

The Australian prawn farming industry is experiencing a notable surge in production, playing a pivotal role in the nation's aquaculture sector. The Australian prawn farming industry grew 126% from $80m to $181m from FY17/18 until FY21/22[7] on the back of domestic demand, which remains strong. Introduced Country of Origin Labelling (COoL) is anticipated to maintain or increase demand for Australian prawns (farmed and wild capture), through competitive advantages over imported prawns.

This growth is anticipated to yield significant benefits to the industry and QLD economy through enhanced employment opportunities, the increased investments in transportation, and a boost in feed investment. Collectively, these initiatives are expected to foster improved social and economic outcomes for communities in the regions where the industry operates, affirming the Australian prawn farming sector's role as a dynamic and integral component of the nation's aquaculture landscape.

The operational aspects of prawn farming are intense contributors of GHG emissions through electricity usage (primarily from pumps and aeration) feed, liquid fuels, processing, refrigeration, and transport.

1.4 Participating members

The study is co-funded by APFA, meaning the carbon calculator study was exclusively extended to APFA members only. Of these members, not all were able to participate due to the timing of the project.

For the sake of confidentiality, the participating members/farms will be kept anonymous.

1.5 GHG emissions in aquaculture

1.5.1 Australia's GHG international reporting frameworks

The Australian government, as a Party to the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol[8] and the Paris Agreement[9], has made commitments to:

- reduce its greenhouse gas emissions
- track progress towards those commitments, and
- report each year on Australia's greenhouse gas emission.

To meet these commitments, the Australian government has established several GHG measurement, accounting, and reporting processes. These include a Full Carbon Accounting Model (FullCAM), National Greenhouse Accounts Factors (NGA) and National Greenhouse and Energy Reporting Scheme (NGERS). These standardised processes ensure consistency across sectors by incorporating international standards. Rigorous frameworks govern emissions assessment, including diverse greenhouse gases, fostering transparency and informing climate policies. Regular updates align methodologies with scientific advancements, ensuring accurate and credible data for effective decision-making and meeting emission reduction goals.

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[7] ABARES Australian fisheries and aquaculture statistics 2022. (See: www.agriculture.gov.au/abares/research-topics/fisheries/fisheries-and-aquaculture-statistics)
[8] The Kyoto Protocol (see: https://unfccc.int/kyoto_protocol
[9] The Paris Agreement (see: https://unfccc.int/process-and-meetings/the-paris-agreement)

1.5.2 What are GHG's?

Greenhouse gases (GHG's) are natural and man-made gases that help trap heat on the earth's surface and include water vapour, carbon dioxide, methane, nitrous oxide, ozone, and some artificial chemicals such as chlorofluorocarbons (CFCs). However, carbon dioxide (CO_2) is the primary greenhouse gas emitted through human activities. In 2021, CO_2 accounted for around 80% of all greenhouse gas emissions from human activities.[10]

The six 'priority' greenhouse gases (GHGs) as listed in the Kyoto Protocol for accounting of GHG profiles are:

- carbon dioxide (CO_2)
- methane (CH_4)
- nitrous oxide (N_2O)
- hydrofluorocarbons (HFCs)
- perfluorocarbons (PFCs)
- sulphur hexafluoride (SF_6)

1.5.3 GHG emission scopes

GHG emissions are reported in three categories or 'scopes' depending on how they are generated or derived, see Figure 1-1. Typical scope 1, 2 and 3 emissions from land based aquaculture are described in Table 2.

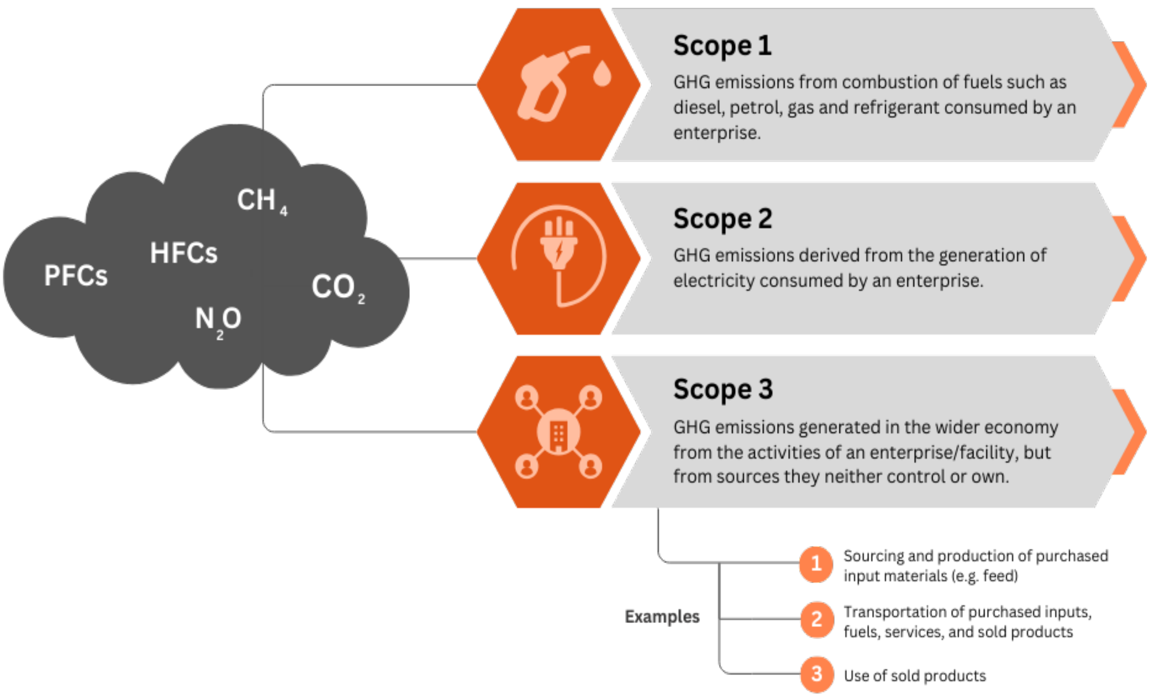

Figure 1-1 Scope 1, 2 and 3 emissions

[10] See: https://www.csiro.au/en/research/environmental-impacts/climate-change/climate-change-qa/sources-of-co2#:~:text=Australia%20is%20the%20world%27s%2014th,per%20cent%20of%20global%20emissions.

Table 2 *Scopes for land-based aquaculture*

Scope	Activities covered	GHG gases	Comments
Scope 1	Fuel use		National Accounts, NIBES. Currently estimated as 6& of total AFF fuel use.
	Diesel	CO_2	Cage culture – Boats and on-board generators. Ponds/tanks – back-up generators
	Petrol	CO_2	Outboard motors
	LPG	CO_2	Heating/cooking
	Non-combustion emissions		National Accounts (NA)
	Ponds - created from wetlands (wetlands lost)?	CO_2 CH_4 N_2O	- - Nominally accounted in NA.
	Emissions from pond operations	CO_2 CH_4 N_2O	- - Accounted in NA but may be incorrect and providing inaccurate picture.
	Cages – created from N_2O, CH_4, CO_2 excretion		Nominally accounted in NA.
	Refrigerant gas losses	CFCs	Not currently accounted.
Scope 2	Electricity consumption Hatchery Growout Processing/ refrigeration	CO_2	Not currently accounted within National Accounts, NIBES Electrical consumption for onshore pond aquaculture is significant.
Scope 3	Feeds consumed	CO_2-e	Major constituent of all 'fed' aquaculture. Currently not estimated.
	Transport	CO_2-e	Transport of equipment, products and people involved in the enterprise
	Storage/refrigeration	CO_2-e CFCs	Third party storage and refrigeration of product in supply chain to consumers. As above.
	Secondary processing	CO_2-e	Third party processing of product in supply chain to consumers.
	Cooking/preparation	CO_2-e	Sometimes calculated by Food Services sector for 'food miles' comparisons.

Scope 3 can also include emissions embedded in supplies and waste.

1.5.4 Drivers for reporting GHG emissions

Key drivers for reporting energy consumption and GHG emissions within the Australian F&A sectors include the following aspects:

- Increased scrutiny by stakeholders, including government bodies, non-governmental organisations (NGOs), shareholders, and consumers.
- Establishing GHG baseline measurements for the F&A sectors, against which future performance can be assessed and potentially compared with other food production sectors.
- An imperative for the F&A sectors to differentiate emissions within the agriculture sector and provide precise, detailed, and distinct assessments of their GHG contributions within the 'Agriculture' category. Currently, this sector is aggregated, making individual contributions less discernible.
- The demand for companies, small and medium-sized enterprises (SMEs), and individuals to possess the capability to quantify their energy consumption and GHG emissions before embarking on mitigation strategies.

The development of more extensive and higher-quality data which may facilitate novel opportunities within the F&A sector.

1.5.5 Cradle to grave

This study has taken a 'cradle to grave' approach to emissions calculation. A 'cradle to grave' approach involves calculating carbon emissions throughout the entire life cycle, including aspects beyond the production phase. Alternatively, a 'cradle to gate' approach narrows the focus to assess environmental impacts from the initial raw material extraction (the 'cradle') to the point where the product leaves the farm (the 'gate').

This life cycle assessment (LCA) spans across various stages, beginning with the cultivation and production of prawn feed, extending through farming operations, processing and packaging, and distribution. This approach provides valuable insights into the environmental implications of prawn farming, allowing for a better understanding of areas where sustainable practices can be implemented to reduce the industry's carbon footprint.

1.5.6 Carbon offsetting or carbon insetting?

In this report, we have explored both carbon 'offsetting' and 'insetting' options for prawn farmers to consider.

Carbon offsetting involves compensating for GHG emissions generated during the production process, by investing in external projects or initiatives that reduce or capture an equivalent amount of carbon. On the other hand, carbon insetting focuses on implementing internal measures and projects within the industry to mitigate emissions directly. This involves adopting sustainable operating practices, improving energy efficiency, and investing in technologies that reduce the carbon footprint, thereby addressing emissions at the source rather than relying solely on external compensation mechanisms.

1.6 Data collection

Data collection (in this case, carbon-related data) is a crucial aspect for an aquaculture business committed to reducing its carbon footprint. The information provides understanding of the environmental impact associated through each area of operations, such as energy consumption, fuel usage, feed consumption and transportation. Businesses are then given the opportunity to produce an accurate carbon footprint, offering insights into key areas contributing to their carbon footprint and therefore explore opportunities to mitigate key areas. This not only helps in compliance with regulatory requirements, but also builds trust with stakeholders (corporate social responsibility), including investors and consumers increasingly valuing sustainable practices.

The analysis of this carbon footprint provides opportunities in to reduce prawn farmers carbon footprint. By pinpointing areas of inefficiency or high carbon footprints, the business can strategically implement measures to optimise resource usage, reduce emissions, and potentially reduce costs. This process of continuous improvement aligns business operations with their overall sustainability goals. This can help underpin and demonstrate the broader industry commitment to responsible and eco-friendly practices.

1.7 Major GHG contributors in prawn farming

The GHG emissions associated with prawn farming stem from several key sources.

The key contributors of GHG were derived from purchased electricity, feed, aquatic N_2O, liquid fuels, refrigeration, processing, and transport. Electricity and feed stand out as the major contributors due to the energy-intensive process of cultivating prawns and processing feed ingredients, particularly fishmeal and fish oil[11]. Other notable GHG contributions are electricity demand for pumping at water intakes and the need to operate paddlewheels and other devices to maintain water circulation and aeration within the prawn ponds. Diesel combustion is derived from vehicle operations and generators. Refrigeration emissions stem from leaks in processing and transportation.

[11] Boyd, C. E., McNevin, A. A., & Davis, R. P. (2022). The contribution of fisheries and aquaculture to the global protein supply. Food Security, 14(3), 805–827. https://doi.org/10.1007/s12571-021-01246-9

The reliance on purchased electricity further escalates GHG emissions if the electricity is generated from a non-renewable source such as fossil fuels (e.g., coal), which have higher emissions factors. Refrigeration systems and refrigerant gas, crucial for maintaining harvested product, contribute to GHG emissions due to energy consumption and unintentional release of refrigerant gases that are typically powerful GHGs with high global warming potential.

These emissions are summarised below in (**Figure 1-2**).

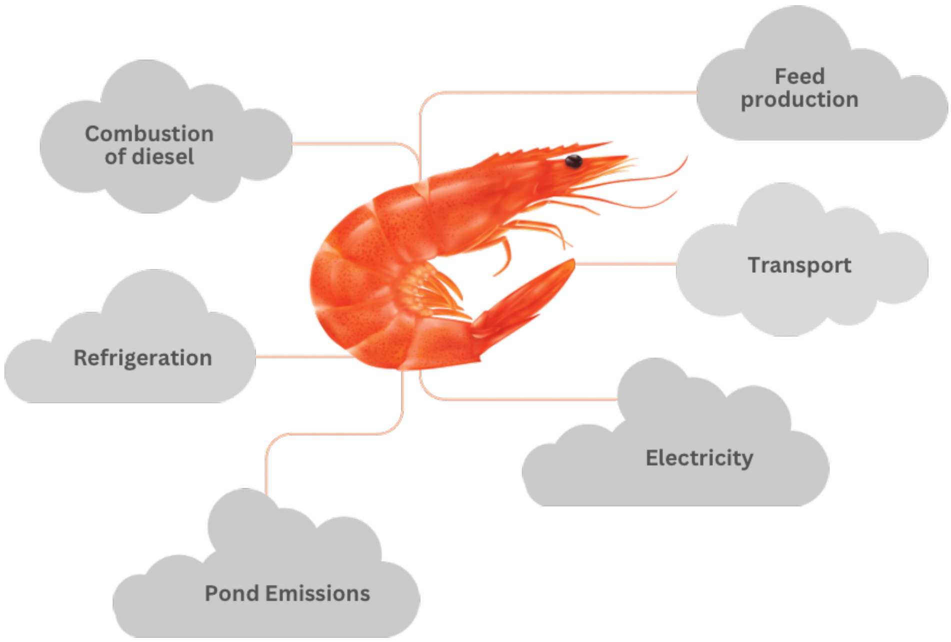

Figure 1-2 The key emission contributors to prawn farmers carbon footprint

2 METHODS

The overall methodology of the project:

- undertook a high-level assessment of the overall carbon footprint of the Australian prawn farming industry;
- provided recommendations to reduce or offset emissions and outlined potential roadblocks that may exists;
- identified future emissions reduction research priority areas; and
- assessed the potential impact of sustainability and carbon neutrality claims/certification on prawn marketability.

2.1 Determining carbon footprint of Australia prawn farming industry

An output of the project was an updated carbon footprint of the Australian prawn farming industry. The carbon footprint was built upon the FRDC project calculation undertaken in 2021, but also considered additional carbon contributors to provide a comprehensive assessment. These components included assessing carbon inputs across different scopes, evaluating emissions and abatement opportunities based on production scale and integrating carbon footprint data with related initiatives for a holistic sustainability evaluation.

Information to undertake the calculation was provided via APFA from members who completed a calculator tool.

2.1.1 Carbon calculator tool

Carbon data and information was collected from APFA members, utilising a tailored carbon footprint calculator tool originally developed by Blueshift Consulting[12], and modified for the project. Figure 2-1 provides a snapshot of the front page of the developed calculator.

The calculator covered Scope 1, 2, and 3 emissions relevant to prawn farming activities “cradle to grave”.

[12] FRDC No 2020/089. Bell, Robert A., Blueshift Consulting 2022, Energy use and carbon emissions assessments in the Australian fishing and aquaculture sectors: Audit, self-assessment, and guidance tools for footprint reduction, Canberra, Australia, (April).

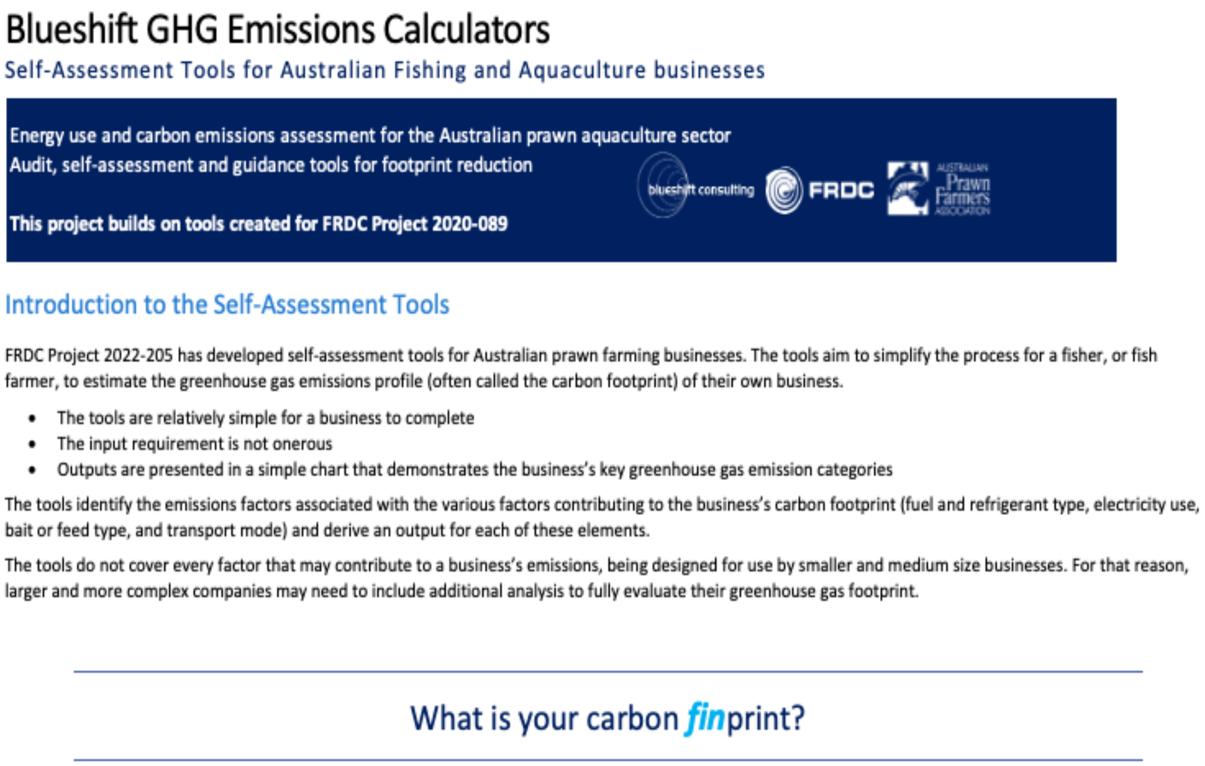

Figure 2-1 Blueshift Consulting's carbon footprint calculator (blueshiftconsulting.com.au/projects)

To calculate an accurate carbon footprint, prawn farmers reported on their carbon inputs (fuels, electricity, feed etc.) and produced prawn weight. This was then entered on a per-farm basis into the carbon calculator, which applied specific emissions factors to determine the CO_2-e value per kilogram of produced prawns (weighted average). This was undertaken for each farm that was able and willing to contribute, and a weighted average CO_2-e per kg of produced prawn figure was determined, as well as the key GHG contributors.

Emissions factors for liquid fuels, refrigerants and for transport are sourced from internationally available databases. These factors change periodically, though not significantly, over time.

Emissions factors for purchased power were sourced from the NGERS, who update figures annually to reflect changes in the emissions profile of Australian power generators. These factors have shown reductions over time as more renewables are added to the energy generation mix and can be expected to decline further in the future.

2.2 Small-scale vs large-scale production

APFA wished to determine whether there were significant carbon footprint differences between small- and large-scale prawn operations. Therefore, carbon data was sought from a selection of farms representing both scales. This included an analysis of scale, production methodologies, technology adoption, and carbon offsetting and reduction opportunities of all farms.

In addition, assessing the data categorised as small- or large-scale operations would potentially allow identification of most appropriate carbon reduction strategies relevant to all farmers within the range of APFA members' size and operations. This included analysis of potential advancements in carbon reduction technology and best practices to reduce carbon emissions and enhance efficiency, and their relevant accessibility by APFA members'.

The completed calculators provided an updated production figure, allowing us to tailor strategies according to producer scale and practicalities within their financial operations. We presented tools and examples that shed light on the implementation costs, providing an overall understanding of the financial implications across varying scales of production.

This project objective was directly influenced by the availability of the prawn farmers to contribute to the project. Unfortunately, the timing of the project aligned poorly with small scale farms, as for many of them it was pond stocking time. Furthermore, the small-scale farms are typically smaller family businesses and are very limited staff wise.

2.3 Opportunities to reduce carbon footprint

Opportunities for Australian prawn farmers to reduce their carbon footprints focussed on emissions mitigation and reduction, firstly through insetting, then by offsetting. Carbon insetting involves a company directly reducing its carbon emissions. Carbon offsetting is more focused on seeking external carbon 'credits' to reduce the operations' carbon footprint.

Opportunities to reduce emissions (by insetting and offsetting) across all three emissions scopes (Scope 1, Scope 2, and Scope 3) included:

- Electricity use reductions;
- GHG associated with feed (i.e. feed choice and efficiency);
- Exploration of blue carbon sequestration;
- Evaluation of emissions and cycles;
- Technological improvements;
- Minimising pond emissions;
- Waste utilisation;
- Refrigeration efficiency and maintenance;
- Carbon offsetting; and
- Supply chain.

2.4 Assessment of roadblocks and challenges to reduce carbon footprint

An objective of the study was to identify potential roadblocks and challenges which may prevent Australian prawn farmers from reducing their carbon footprints. It is imperative to identify and understand these obstacles, and to develop effective approaches to work-around or overcome them.

A further objective was to increase awareness within the industry of the positive impacts both measuring carbon footprints and reduction activities. The overall goal was to develop a collective understanding of the benefits of carbon reduction for greater industry sustainability but also cost reductions and product value enhancement. A range of opportunities were investigated to reduce these identified risks and barriers.

2.5 Research priorities

An objective of the project was to develop a list of future R&D priorities for APFA and industry. All priorities were given a cost/benefit review to guide prioritisation of future projects. This provides APFA guidance with planning future R&D and continually moving forward as an industry.

2.6 Assessing opportunities to generate benefits from lowered carbon footprints

A literature review and assessment of similar opportunities utilised in different industries was undertaken to identify potential areas for deriving direct and indirect benefits from efforts to reduce the carbon footprint within the Australian prawn farming industry. These opportunities allow for enhanced sustainability and corporate social responsibility, reduced costs (through energy and feed efficiency enhancement), carbon offset programs, and certification and marketing strategies associated with GHG reduction initiatives. These endeavours were envisioned not only to positively impact the environmental aspects of the industry but also to foster economic growth and enhance its environmental and social governance (ESG), thus contributing to a sustainable future.

2.6.1 Initiatives and certification

Third-party certification schemes are becoming increasingly concerned with carbon accountability. An assessment or audit of operator's carbon data is forming a significant factor in overall sustainability assessments of businesses and industries, and in investment decisions. This part of the study involved a literature review and comparative analysis to investigate sustainability and carbon neutrality impact on prawn marketability, as well as the possibilities for involving any certifications or initiatives.

3 RESULTS

3.1 Updated carbon footprint

The key contributors to prawn farms' carbon footprint (expressed as CO_2-e) are purchased electricity, emissions (including N_2O) resulting from the use of high-protein feed and refrigerant use or leakage. Other contributors include on -farm liquid fuels, and off-farm transport related emissions.

Table 3 The weighted average GHG emissions from prawn farm responses (kg CO_2-e per kg of produced prawns)

Scope 1			Scope 2	Scope 3		Total
Liquid fuels	Refrigerants	Aquatic N2O	Electricity	Feed	Transport	
0.41	1.24	1.30	4.25	2.36	0.12	**9.68**

The observed range of carbon footprint among farms surveyed (noting that no small farms <100 tonnes of production participated in the study) is 8.7 – 12.7 kg CO_2-e per kg of produced prawns, with a weighted average of 9.68 kg CO_2-e per kg. This number is lower than previous estimates, driven by reductions in the Queensland grid's emissions factor with its reducing reliance on coal, and possibly by the fact that surveys received to date have been from larger, more efficient farms generally with less purchased power (for pumping, aeration, and recirculation) than earlier observations.

Imported farmed prawn product of Asian and South Asian origin has been assessed as having a carbon footprint of 12 – 14 kg CO_2-e per kg of produced prawns, before processing and transport to sale destination is considered[13]. On this comparison, Australian farmed prawns have a lower carbon footprint than the imported farmed product when sold into the Australian market.

3.2 Scope 1

3.2.1 Fuel used on farm

Fuel use on farm is considered Scope 1.

Fuel (diesel, petrol and gas) is used on farms for fixed and mobile machinery, and for heating. Fuel use represents a relatively small proportion of Australian prawn farms' carbon footprint. The reported carbon footprint attributable to fuel use ranged from 0.28 – 0.64 kg CO_2-e per kg of produced prawns, with a weighted average of 0.41 kg CO_2-e per kg.

This represents 4.2% of a typical Australian prawn farm's carbon footprint.

3.2.2 Refrigerant

Refrigerant emissions are considered Scope 1.

Refrigerant use represents a sizeable proportion of Australian prawn farms' carbon footprint. The refrigerant gases commonly reported in the survey have very high greenhouse warming potentials: 1,300 – 4,000 kg CO_2-e per kg of refrigerant. This means that relatively small losses or leakages of these gases can lead to significant carbon footprint outcomes.

[13] MacLeod, M. H.-U.-R. (2019). Quantifying and mitigating greenhouse gas emissions from global aquaculture. *FAO Fisheries and Aquaculture Technical Paper No. 626*, 49.

Newer generation refrigerant gases are available but are typically expensive and not necessarily compatible with existing refrigeration systems. This means that effective maintenance of existing systems is possibly the most capital-effective way to minimise emissions from this part of the business.

The reported carbon footprint attributable to refrigerant purchases or leakages ranged between 0.26 and 2.9 kg CO_2-e per kg of produced prawns, with a weighted average of 1.24 kg CO_2-e per kg. This relatively large variance between farms is likely attributable to significant leaks in refrigeration systems.

This represents 12.8% of a typical Australian prawn farm's carbon footprint. While a relatively low cost item compared to fuel for a typical farm, the carbon footprint of refrigerant use is typically far larger than the footprint attributable to fuel use.

3.2.3 Pond emissions

Pond emissions are considered Scope 1.

Emissions of methane CH_4 and nitrous oxide N_2O may be significant contributors to overall GHG emissions from prawn ponds. In aquaculture systems, N_2O is mainly produced from incomplete decomposition of wastes (faeces, uneaten food, mortality, etc). Total emissions depend on the nitrogen content of feed and fertiliser, and the nitrogen retained in harvested prawn biomass.

The carbon footprint attributable to N_2O was not reported by prawn farms. This study uses an assumption of 1.30 kg CO_2-e per kg of prawns harvested, based on figures published by MacLeod et al[14]. This represents 13.4% of the typical prawn farm's carbon footprint.

3.3 Scope 2

3.3.1 Electricity

Purchased power emissions are considered Scope 2.

Prawn farms tended to report their entire operations' purchased power consumption as a standalone value, that included the electricity consumed performing on-farm processing. This ranged between 3.9 and 8.9 kWh per kg produced prawns.

It is not clear from the survey results whether this wide range of electricity use could be attributed to differences in farm layout, pump or aeration technology, or mortality events.

To note, there are significant differences in power consumption reported for paddlewheels compared to alternative aeration/circulation technologies. If alternative technologies can be made to work within a farm's production system, the benefits would be apparent both in lower operating costs (from lower power use) and in the farm's overall carbon footprint.

Using the Queensland grid's average emissions factor of 0.88 kg CO_2-e per kWh, this means that the carbon footprint attributable to purchased electricity ranged between 3.4 and 7.8 kg CO_2-e per kg of produced prawns, with a weighted average of 4.25 kg CO_2-e per kg. This represents 43.9% kg CO_2-e per kg of a typical Australian prawn farm's carbon footprint.

[14] MacLeod, M. H.-U.-R. (2019). Quantifying and mitigating greenhouse gas emissions from global aquaculture. *FAO Fisheries and Aquaculture Technical Paper No. 626*, 49.

It is worth noting that the Queensland grid's emissions are the highest of any state except Victoria, owing to the State's reliance on coal fired power stations, as per Table 4. As the Queensland grid incorporates more renewable energy generation, the grid's overall emissions factor can be expected to reduce over time – hence reducing prawn farms' carbon footprint in the longer term.

Table 4 Purchased Electricity GHG Emission Factors (EF) of all Australian states

Purchased Electricity GHG EFs State or Territory	Emission factor kg CO_2-e/kWh
Victoria	0.92
Queensland	0.88
South Australia	0.33
NSW	0.79
South West Interconnected System (SWIS) in WA	0.55
North Western Interconnected System (NWIS) in WA	0.62
Darwin Katherine Interconnected System (DKIS) in the NT	0.61
Tasmania	0.18
Northern Territory	0.61

There are schemes that allow electricity buyers to offset the emissions of their purchased power. Ergon's standard tariff to offset 100% of power emissions is 6.22 cents per kWh. This equates to a carbon price of approximately $70 per tonne. A farm seeking to offset its purchased power emissions by this means would face added electricity costs equivalent to 24 – 55 cents per kg of produced prawns, the amount being relative to the farm's power use efficiency. Any decision to follow this strategy would have to be accompanied by a comparison of offset alternatives including self-generating renewable energy; and analysis of what, if any, price premium might be achievable to offset this additional production cost.

Prawn farms are generally aware of their energy use and ability to forecast it. This predictability, combined with scale, means there may be merit in the concept of prawn farms connected to the same grid, combining purchasing power to be able to negotiate better terms for lower or zero-emissions energy provided through the grid.

3.4 Scope 3

3.4.1 Feed

Feed emissions are considered Scope 3.

There are a range of contributors to the embodied carbon footprint of produced high-protein feed, which are listed below. The NGERS ascribes emissions of 1.375 kg CO_2-e per kg of feed utilised. A higher FCR then will contribute to a higher carbon footprint.

The key GHG contributors derived from the embodied carbon footprint of feed are:

- Feed blending and transport;
- Fishmeal;
- Crop land use change;
- Crop energy use;
- Production of fertiliser for crops; and
- Feed – other materials.

The emissions associated with the embodied carbon footprint of feed as above is estimated as between 2.27 – 2.76 kg CO2-e per kg of produced prawns, with a weighted average of 2.36 kg CO_2-e per kg. This represents 24.4% kg CO_2-e of a typical Australian prawn farm's carbon footprint.

3.4.2 Processing

Processing emissions, if conducted on-farm using purchased power, are considered in Scope 2. If processing is conducted off-farm, by a third party, processing emissions are considered in Scope 3.

Farms that responded to the study mostly did not report electricity usage specific to processing their product on-farm. This means that this significant percentage of purchased electricity use is generally reported at a whole-of-farm level: given this, most study respondents correctly omitted specifying any form of processing so as to avoid double-counting that part of their energy use. Accordingly, these emissions are captured as part of the Scope 2 emissions from purchased power.

For those that did report specific processing electricity usage, the energy used was highly consistent with the default values for processing that are included in the APFA carbon calculators. This gives us confidence in the carbon calculators, though there may be impetus to change future versions of the calculator to allow prawn farmers the option to either input their operations' exact processing electricity usage; or to use the calculator's default values.

A fair assumption might be that processing costs do not vary too much between farms.

Electricity use for processing is typically in the range of 0.6 – 0.7 kWh per kg of produced prawns processed or 7-8% of a typical Australian prawn farm's carbon footprint.

3.4.3 Transport

Transport off-farm emissions to the point of sale is considered Scope 3.

Transport off-farm emissions are a relatively minor contributor to prawn farms' carbon footprints, despite product being trucked reasonably long distances south to market. This is because long-haul road transport is relatively efficient in terms of its carbon footprint, expressed as kg CO_2-e per tonne per kilometre travelled.

The reported carbon footprint attributable to product transport ranged between 0.12 and 0.16 kg CO_2-e per kg of produced prawns, with an average of 0.12 CO_2-e per kg. This represents 1.2% of a typical prawn farm's carbon footprint.

This is a marked distinction to industries that rely on long haul air transport to deliver product to market, where the transport footprint can approach 50% of the product's total footprint.

4 DIFFERENCES BETWEEN SMALL AND LARGE PRAWN FARMS

At time of writing, insufficient survey responses have been received from prawn farmers to be able to describe difference and provide reduction advice on their respective carbon footprint of large against small prawn farms.

5 PATHWAYS AND OPPORTUNITIES TO REDUCE FARMERS CARBON FOOTPRINT – ENTERPRISE AND INDUSTRY LEVEL

5.1 Electricity usage

Carbon emissions derived from electricity usage on farm are the largest contributor (44% of the carbon footprint of surveyed farms) and if reduced, presents dual improvement opportunities through a reduction of both emissions and costs. The carbon intensity of electricity varies greatly depending on fuel source. As a guide, coal has a carbon intensity of about 1,000g CO_2/kWh, oil is 800g CO_2/kWh, natural gas is around 500g CO_2/kWh, while wind and solar are all less than 50g CO_2/kWh.

It is worth noting that QLD is reducing its reliance on coal for grid power, therefore reducing the emissions factor and prawn farmers carbon footprint without any involvement.

5.1.1 Renewable energy

Transitioning to renewable energy will allow prawn farmers to reduce on-farm emissions. The options for prawn farms to utilise renewable power are to either purchase renewable energy or produce renewable energy. The simplest of the two is to purchase renewable energy that is becoming increasingly available in Queensland.

Queensland's 2030 target is to reduce emissions, create new jobs and diversify the state's economy by establishing a 50% renewable energy target by 2030. Queensland is accelerating towards its renewable energy targets and now boasts 52 large-scale renewable energy projects (operating, under construction or financially committed). This represents more than $11b of investment, around 8,500 construction jobs, over 6,000 megawatts (MW) of clean energy and more than 14 million tonnes of avoided emissions each year.

5.1.1.1 Current renewable initiatives in Queensland

The following renewable energy initiatives are underway in QLD, outlining the possible opportunities for prawn farmers. There are several examples for prawn farmers to explore and potentially seek a renewable project of their own in collaboration with the QLD government.

These initiatives include:

- Queensland renewable energy zone (QREZ)
  - The $145 million QREZ initiative will grow Queensland's position as an investment destination for large-scale renewable energy projects, creating more regional jobs.
- Queensland Renewable Energy and Hydrogen Job Fund
  - The Queensland Renewable Energy and Hydrogen Jobs Fund allows energy government-owned corporations to increase ownership of commercial renewable energy and hydrogen projects, and support infrastructure, including in partnership with the private sector.
- Solar 150 projects
  - The Solar 150 program supports 4 projects through long-term revenue guarantees:

    - Edify Energy's Whitsunday Solar Farm
    - Genex's Kidston Solar Farm
    - Canadian Solar's Longreach Solar Farm
    - Oakey Stage 1.
- Renewables 400
    - The Queensland Government initiated the Renewables 400 reverse auction for up to 400MW of renewable energy capacity. Ten projects were shortlisted to progress to the next stage. CleanCo delivered Renewables 400, given the integral role it plays in the government's commitment to a clean energy future.

There are several renewable power generation initiatives throughout QLD, and to meet the states 2030 goals for decarbonisation, the QLD government is becoming increasingly interested in investing in renewable projects, providing opportunities for businesses to transition to renewable energy and reduce their carbon footprint. Moreover, the QLD government is also providing significant investment to grow the states aquaculture industry, and alignment of these two key priorities would be mutually beneficial and provide significant upside at government and industry level.

The following link (https://www.business.qld.gov.au/running-business/support-assistance/mapping-data-imagery/maps/electricity-generation) provides a map of all renewable projects in QLD for solar power, wind power, and hydro power. Solar power is the most accessible renewable power option throughout QLD. This outlines that there are several viable opportunities for prawn farmers to transition to renewable energy and reduce their overall carbon footprint. It also shows QLD's ongoing renewable development needed for the state to transition its grid away from coal, reducing the grids emissions factor and helping to reduce prawn farmers carbon footprint without any capital investment.

5.1.1.2 Renewable energy generation on farm

The more complex method is for prawn farmers to produce their own renewable energy. Without significant capital investment, opportunities for farmers to transition to renewable power sources are limited. However, a collective approach for farmers in close proximity of each other is to band together and invest in renewable energy production that provides benefits to multiple farms. In most cases this is unpractical due to the distance between prawn farms.

The QLD government provides plentiful information for businesses to install and transition to renewable power, with the most appropriate being solar power. Due to the high amount of power required to operate a prawn farm 24/7, this is a viable opportunity to reduce the business electricity bill and carbon footprint. Collectively with efficient battery storage, this could significantly reduce electricity derived costs and emissions.

5.1.1.3 Collective renewable energy

Another opportunity for prawn farmers is to undertake a collaborative approach in producing or purchasing renewable energy. This presents a chance to transition energy usage on farm completely, or for some key operations, whilst costing significantly less capital investment. This needs to be a collaborative initiative between close proximity farms, with the easiest and most accessible opportunity being solar power.

The QLD government supports solar farm opportunities for land-based marine aquaculture through investment opportunities for Aquaculture Development Areas (ADA's), which are listed below (Table 5 A list of Aquaculture Development Areas provided by the QLD government.). There are currently no prawn farms within these areas, but there is a potential to seek investment for a collective prawn farmer solar farm to support prawn farms nearby. This would require significant R&D an agreement between contributing/investing farms and support by the QLD government.

Table 5 A list of Aquaculture Development Areas provided by the QLD government.

ADA site	Name	Local Government Area	Size (ha)
1	Sleeper Log Creek/Leichhardt Creek	Townsville City Council	319
2	Abbot Bay/Good Fortune Bay	Whitsunday Regional Council	316
3	Bloomsbury	Mackay Regional Council	2126
4	Rockhampton/Casuarina Creek	Rockhampton Regional Council	2278
5	Rockhampton/Raglan Creek	Rockhampton/Gladstone Regional Council	1430
6	Gladstone/Calliope River	Gladstone Regional Council	579
7	Macknade	Hinchinbrook Shire Council	498
8	Halifax/Braemeadows	Hinchinbrook Shire Council	1476

Figure 5-1 Map of Aquaculture Development Areas in Queensland.

5.1.2 ecoBIZ program

The Business Chamber Queensland's ecoBiz program is a free service that helps Queensland businesses cut costs across not only their energy, but also water and for a variety of businesses, institutions and organisations across all sectors, helping maximise their savings.
Businesses of all sizes can benefit.

The program also provides free benchmarking assistance to help track resource use, as well as one-on-one on-site coaching sessions with a sustainability expert to help identify opportunities to implement initiatives to cut energy costs, reduce carbon emissions and be more sustainable in energy, water, and waste.

For prawn farmers, the ecoBiz program could be beneficial by providing tailored assistance to reduce their carbon footprint and overall environmental impact. Through energy efficiency audits, water conservation measures, waste management strategies, and sustainability coaching, prawn farmers could optimise their operations for environmental sustainability. This could involve upgrading equipment, implementing renewable energy solutions, recycling water and nutrients, sourcing feed from sustainable suppliers, conserving habitats, and offsetting remaining emissions through carbon offset projects. By participating in ecoBiz, prawn farmers can not only mitigate their environmental impact and potentially costs, but also enhance their long-term viability and resilience in an increasingly environmentally conscious market.

5.1.3 Energy audit – The Business Energy Savers Program

Completing an energy audit is the first step to identify where energy use savings could be made on prawn farms. In QLD, assistance for farmers to undertake energy audits is available through the Business Energy Savers Program. The overall objective of The Business Energy Savers Program is to assist regional QLD businesses in reducing energy costs and is part of the QLD Governments $2 billion affordable energy plan. The Energy Savers Programs includes the Energy Savers Program Plus Extension (ESPPE) delivered by QLD Farmers Federation (QFF) provides free energy audits for agricultural customers representing a valuable opportunity for prawn farmers. By tapping into the insights derived from these audits, prawn farmers can reduce their electricity costs by using electricity more efficiently. Implementing tailored energy-saving measures recommended in these audits could reduce energy usage, leading to substantial cost savings and a reduced carbon footprint for prawn farms. Furthermore, the installation of real-time energy meters offers precise data on energy consumption patterns, allowing prawn farmers to make informed decisions to optimise their operations.

QFF have facilitated energy audits for more than 300 farms across various sectors since 2015 that have pinpointed potential annual savings of 7.5 million kWh, equating to an estimated $3 million in savings and a reduction of 6,000 tonnes of carbon emissions. If all recommendations from these audits were implemented, energy consumption in the monitored areas could decrease by approximately 40%. Currently, more than half of the farms involved have already put into action the recommendations from these audits. Over 50 real-time energy meters have been installed on farms to provide additional insights into their energy consumption patterns.

It is recommended that APFA engages with The Energy Savers Program and encourage members to undertake this free audit process, to identify opportunities reduce energy use, costs and carbon emissions.

5.1.3.1 Case study – Crowley Aquaculture Farm (Barramundi)

The freshwater Barramundi farm at Cowley Beach[15] consists of 38 ponds with a combined total area of approximately 55 hectares. Annual production is 1,150 tonnes of whole fish. The ponds are aerated with paddle aerators to provide the required oxygen levels, with water supplied by several submersible river pumps and centrifugal booster pumps. The farm has its own processing facility where the fish are prepared for transport.

The total annual energy consumption of the farm is around 3,500,000kWh at a cost of over $850,000. The farm also has 4 diesel generators to support the pond's supply, which operate in an alarm auto-start and consume 500L of diesel every 8 hours.

To reduce energy consumption and costs onsite, recommendations in the audit included:

1. A restructure of the current operating tariff.
2. Improving pond aeration control (paddle wheel) using sensors.
3. Upgrading impeller in river pumps to improve efficiency.
4. Installing a 60kW solar PV system in a combined supply configuration.

Table 6 Audit recommendation and savings for Crowley Aquaculture Farm (Barramundi)

Recommendation	Estimated Cost to Implement ($)	Payback Period (years)	Energy Savings (kWh)	Cost Savings ($)	Emission Savings (tCO_2-e)
Restructure of tariff	—	—	—	41,450	**—**
Sensors in pond aerator control	814,000	6.9	645,000	116,825	**522**
Pump upgrade	30,000	3.2	49,950	9,320	**62**
60kW solar PV	108,000	4.8	110,000	27,655	**88**
Combined supply for solar PV	500,000		—	100,000	**—**
Total	**1,452,000**	**5.5 years (Average)**	**805,000**	**295,000**	**672**

The energy audit recommends two significant strategies for improved efficiency on barramundi farms. Firstly, it proposes installing real-time dissolved oxygen (DO) sensors to automate paddle wheel operations and enhance pond aerators. These sensors provide crucial data every 4 minutes on DO levels and water temperature, preventing fish stress by identifying dips in DO levels, particularly at night. Additionally, they monitor aerator conditions, aiding in biofouling detection and assessing gearbox and motor health. Simultaneously, the audit suggests replacing labour-intensive manual chemical tests, reducing costs and labour time.

Secondly, the audit proposes a solar PV system that consolidates various supply points into one, potentially reducing fixed metering charges, energy rates, and offering tariff benefits. This consolidation aligns energy consumption with solar generation, effectively reducing overnight energy loads. Alternatively, dispersed PV systems across different buildings present less vulnerability to weather conditions and voltage fluctuations. However, implementing individual systems at each supply point requires more management and incurs additional costs and time. Implementing these

[15] See: www.qff.org.au/newsroom/case-studies/cowley-aquaculture-farm/

recommendations could yield a substantial 23% decrease in energy consumption, a 35% cost reduction, and prevent 672 t CO_2-e carbon emissions annually at current production levels.

5.1.4 Energy efficient plant and equipment

Typically within the prawn industry, around 10 aerators per hectare of pond area are used to maintain DO load in ponds. These aerators operate on main supplied electricity and account for 70-80% of the total energy consumption on farms. This suggests that during the peak production period, around 6,000 2hp aerators are concurrently operational within prawn industry ponds substantially contributing to carbon emissions of Australian prawn farming.

Innovative technologies, such as aeration systems capable of automatic activation and deactivation, can play a crucial role in maintaining ideal oxygen levels for prawns, maintaining survival rates and growth, all while conserving energy. Furthermore, the integration of these systems with local electrical grids to harness renewable energy sources presents an opportunity for substantial reductions in carbon emissions.

Controlling biofouling on pond aerators is also believed to be an effective method to reduce energy usage. Savings of up to $280/ha per crop cycle, and a reduction of break-down rate (less reliance on backup diesel generation) were seen in a 2011 study[16]. The approximate expense attributed to biofouling totals at least $1,000 per hectare per crop, encompassing supplementary expenses for labour, maintenance, and electricity costs.

Overall energy efficient plant and equipment will be effective in all farms, but particularly in the warmer water northern prawn farms as pump and aeration systems need to work harder and require more electricity to meet optimum DO levels.

5.2 Feed

Feed inputs constitute a significant contributor to the carbon footprint of prawn farms. Prawn feed is a significant contributor of carbon in aquaculture due to the carbon emissions produced during capture of wild fish for fish meal and oil ingredients, energy consumption in feed processing and transportation. Farmed prawns require a high protein diet compared to other cultured species, meaning emission derived from feed is generally higher.

Formulated feeds account for a large portion of GHG emissions of a farming operation. Feed includes Scope 3 emissions, yet it has not been factored into the Australian Greenhouse National Accounts or NGERS of emissions profiles for aquaculture producers. The absence of this data poses a challenge for the industry and businesses seeking to represent its carbon footprint accurately. As a result, the Australian National Accounts for the aquaculture industry may exhibit under-reporting due to the absence of a Scope 3 emissions assessment that includes feed.

Prawn feeds are formulated from fish meal, sourced from wild catch fisheries (primarily sardines and anchovies), discard fish or from fish post-processing wastes (and processed to extract these components) processed animal proteins, as well as terrestrial crops (soybeans and grains), micro-nutrients, and vitamins. After the nutritional needs of feeds have been considered, the addition of environmental objectives are now being considered by feed responsible manufacturers as reducing emissions related to feeds has become critical to advancing sustainability in prawn farming.

[16]Mann, D. (2013). Controlling biofouling of pond aerators on marine prawn farms. Australian Seafood CRC and FRDC Project 2011-734.

Efforts to reduce the carbon footprint of feed ingredients involve implementing sustainable agricultural practices, auditing, and improving feed production processes, reducing waste, and investigating sustainability (i.e. life cycle assessments) of emerging alternative sources of protein and nutrients. Life cycle assessments (LCAs) are used to reveal the environmental impact of different feed ingredients considering GHG emissions related to land use and energy consumption, and other sustainability issues such as water usage throughout cultivation and processing. Ultimately, reducing the carbon footprint of feed ingredients involves a combination of sustainable sourcing, efficient production methods, and ongoing research into alternative, environmentally friendly feed sources.

Feed companies are essential to making changes in feed production to reduce carbon emissions from Australian prawn farming. Consequently, choosing feed manufacturers with low carbon footprints and carbon reduction objectives is vital due to their goals in mitigating environmental impacts derived from feed production. By embracing efficient energy use, employing eco-friendly raw materials, and leveraging innovative technologies, these manufacturers may significantly reduce carbon footprints of feeds. Supporting such manufacturers supports the aquaculture industry's efforts to decrease its environmental impact, ensuring a more sustainable future by lowering overall emissions and fostering environmentally responsible practices in the production and use of aquafeeds. Choosing high quality feeds produced by these manufactures will enhance feed efficiency, ultimately decreasing costs and the farms to reduce their Scope 3 feed emissions without any further APFA funded R&D.

It is important to highlight that reducing the carbon footprint of manufactured diets typically entails trade-offs with other sustainability metrics emphasised by certification bodies. For instance, while wild capture fishmeal generally has a lower carbon footprint compared to many alternative protein sources, it contributes to a higher Fish in: Fish out (FIFO) ratio due to its higher Fishmeal Inclusion Fishery Factor (FIFF). Therefore, when making feed choices on farm, both reducing carbon emissions and decreasing reliance on forage fishmeal needs to be taken into account.

5.2.1 Feed input changes

During the early stages of growth, prawns require high protein content in feed (roughly 43% protein), and then typically move to a low protein diet (roughly 37% protein). Of the total feed used in production, 30% is a low protein diet (starter diet) and 70% is a high protein diet (grower diet). Low animal protein formulated feed contributed 1kg of CO_2-e per kg of prawn produced, whereas high animal protein formulated feed contributes 2.2kg CO_2-e per kg.

As prawns mature, the need for high-protein feed decreases, allowing for a shift to lower protein content feeds. Adjusting the protein percentages at different growth stages reduces the overall carbon footprint of prawn farming, potentially reducing environmental impact by lessening reliance on high-carbon feed ingredients and optimising feed formulations for sustainable farming practices.

However, a shift to lower protein diets may slow growth rate, leading to increased harvest periods, prolonged electricity use and feed amounts, possibly leading to an increased overall carbon footprint. This requires R&D and feasibility studies on individual farms to investigate if it is suited to the farmers operations.

5.2.2 Feed Conversion Ratio (FCR)

Another key method to reduce the carbon footprint derived from feed is to source a high quality feed that can improve FCR through increased efficiency. This also lowers costs associated with feed.

Aquaculture feed poses an environmental risk due to the large carbon footprint contributed through decomposition of excess nutrients (CH_4 and NO_x). Consequently, reducing the FCR to enhance feed efficiency, ultimately reducing costs and lowering the users carbon footprint. The use of technology to improve feed efficiency is essential increasing the FCR.

By facilitating management and assessment of the feeding process through the use of technology, prawn farmers can increase on farm feed efficiency. Innovative feed technologies can ensure the optimal delivery of food quantities at the appropriate times across a maximum feed area. This will decrease their carbon footprint and costs associated with feed.

BioMar's AQ1 System is one of several acoustic feeding options available to industry. These acoustic feeders offer a viable opportunity for prawn farmers to increase their feed efficiency, ultimately lowering costs and on farm feed emissions contributing to their overall carbon footprint.

Utilising feed technology can result in enhanced prawn growth and an improved FCR therefor having a positive impact on the farms environmental stance by reducing its carbon footprint and waste while also reducing feed associated costs.

5.3 Blue carbon sequestration

Blue carbon sinks include seagrass meadows, tidal marshes and wetlands, and mangrove forests, and are highly effective at sequestering carbon. These ecosystems store and sequester carbon dioxide from the atmosphere and convert it to plant growth, such as leaves, stems, or roots.

On a global scale, there has been a significant increase in blue carbon emissions primarily attributed to the adverse impacts of human activities on coastal environments, including mangrove swamps, salt marshes, and seagrass meadows. However, a promising avenue for reversing this trend and promoting the restoration of coastal ecosystems while sequestering blue carbon is the adoption of sustainable aquaculture practices.

These valuable coastal ecosystems are abundant in QLD. The proximity and location of prawn farms constitutes an opportunity to conserve, restore and regenerate those ecosystems while achieving carbon reduction.

5.3.1 Blue carbon sequestration in QLD

Blue Carbon Lab[17] is extensively exploring QLD blue carbon potential, including mapping of Blue Carbon stocks and sequestration rates. The following key findings were found:

- Mangrove forests and seagrass meadows within the Great Barrier Reef catchments hold a blue carbon stock of over 111 million tonnes of carbon, which is equivalent to the annual emissions of ~87 million cars.
- These ecosystems would sequester ~251 million tonnes CO_2 equivalent by 2100.
- Six local government areas hold almost 70% of all the blue carbon in the Great Barrier Reef catchments. The top six blue carbon hotspots include the Cook Shire, Livingstone Shire, Gladstone Regional, Burdekin Shire, Isaac Regional and Whitsunday Regional.
- If considering the Natural Resource Management (NRM) regions, Cape York and Fitzroy regions hold more than 60% (~130 million tonnes of carbon) of the predicted carbon stocks.

Blue Carbon Lab's goal is to help QLD turn carbon into income by helping farmers to earn cash whilst spread risk and diversify production and strengthening their future on the land through expanding carbon farming. Blue carbon covers a wide range of carbon farming activities including as restoration and reforestation, investing in projects that improve coastal and wetland ecosystems (mangroves

[17] Blue Carbon Lab. (n.d.). Retrieved from www.bluecarbonlab.org

forests) through restoration and reforestation. APFA or individual prawn farmers could engage with a firm specialising in blue carbon activities, to explore an industry wide carbon sequestration initiative to reduce emissions, or suitable blue carbon offsetting opportunities.

5.3.2 Blue carbon sequestration opportunities for prawn farmers

Blue carbon sequestration is an innovative and sustainable approach to mitigating climate change, particularly relevant for Australian prawn farmers. By harnessing the natural carbon capture capabilities of coastal ecosystems like mangroves, seagrasses, and tidal marshes, prawn farmers can not only enhance their environmental stewardship but also contribute to carbon reduction efforts. 'Blue carbon' opportunities that have benefit to prawn farmers need to be identified and investigated, ensuring their alignment and benefit to industry.

5.3.3 Mangrove restoration

Mangroves play a pivotal role in global ecosystems through sequestering carbon. Mangroves sequester carbon at up to four times the rate of terrestrial forests, making them tremendous allies in our struggle for net-zero carbon emissions by 2050. Pond-based prawn farming presents farmers with a viable opportunity to engage in mangrove restoration in close proximity to their farms. Currently, mangrove reforestation activities are not officially recognised by regulators and do not lead to a direct reduction in prawn farmers carbon footprint, however, can be used as carbon offsetting through some organisations. Mangroves offer a wide array of ecosystem benefits, including serving as a breeding ground for marine life, a habitat for migratory species, safeguarding coastal communities, filtering pollutants, and sequestering carbon – preserving mangroves preserves these benefits.

Mangrove restoration should encompass a small-scale approach, striving to minimise habitat fragmentation by physically connecting existing mangrove ecosystems. This could involve nearby ecosystems, or an on-farm approach.

5.3.4 Clean Energy Regulator - *Tidal restoration of blue carbon ecosystems*[18]

The blue carbon method facilitates the accrual of Australian Carbon Credit Units (ACCUs) through projects that eliminate or alter tidal constraints, permitting the reintroduction of tidal flow to specific land areas. This leads to the rehydration of coastal wetland ecosystems that were either completely or partially drained, and the transformation of freshwater wetlands into brackish or saline environments. The methodology allows for the generation of ACCUs based on the establishment of coastal wetland ecosystems resulting from project activities.

Prawn farmers can actively engage with the Clean Energy Regulator's Tidal Restoration of Blue Carbon Ecosystems[19] method to effectively reduce their carbon footprint. This method involves the restoration of tidal areas to enhance blue carbon sequestration, which plays a crucial role in reducing their climate footprint.

Prawn farmers can consider integrating tidal restoration projects into their operations. This may involve the rehabilitation of mangroves, saltmarshes, and seagrasses, which act as natural carbon sinks. The Clean Energy Regulator provides guidelines on implementing these projects, outlining the steps necessary for quantifying, and reporting carbon sequestration benefits. By incorporating tidal

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[19] See: https://www.cleanenergyregulator.gov.au/ERF/Choosing-a-project-type/Opportunities-for-the-land-sector/Vegetation-methods/tidal-restoration-of-blue-carbon-ecosystems-method

restoration initiatives, prawn farmers not only contribute to environmental conservation but also earn carbon credits through the Emissions Reduction Fund (ERF).

Active participation by prawn farmers in the Tidal Restoration of Blue Carbon Ecosystems method, Queensland prawn farmers can play a vital role in fostering sustainability and offsetting their overall carbon footprint.

5.3.4.1 Blue carbon accounting model (BlueCAM)

The Blue Carbon Accounting Model (BlueCAM) serves as a framework for assessing and quantifying the carbon dynamics within blue carbon ecosystems, including coastal habitats such as mangroves, saltmarshes, and seagrasses. This model incorporates various parameters, such as vegetation type, biomass, and soil characteristics, employing advanced statistical and computational methods to estimate carbon stocks and emissions.

Prawn farmers can utilise BlueCAM to enhance their environmental stewardship and reduce their carbon footprint. By applying the model to assess the impact of their activities on coastal ecosystems, farmers gain insights into the carbon benefits associated with measures like tidal restoration or wetland conservation. Farmers can then implement practices that not only contribute to the preservation of blue carbon ecosystems but may also make them eligible for ACCU's through programs like the Clean Energy Regulator's Tidal Restoration of Blue Carbon Ecosystems method.

BlueCAM is an effective tool for prawn farmers looking to align their operations with sustainable practices and reduce their overall carbon footprint.

5.4 Waste utilisation to reduce carbon footprint

If not treated adequately, excess nutrients in pond wastewater can decompose and emit GHG's (methane/ CH_4) into the atmosphere. If treated, wastewater systems can filter pond wastewater, allowing the treated pond water to be utilised in a variety of ways (fertiliser, reforestation, etc), providing a solution that both sequesters and abates carbon.

5.4.1 Integrated Multi-trophic Aquaculture (IMTA)

IMTA systems pose a viable opportunity to utilise wastewater effluent derived from prawn farming operations, reducing their carbon footprint and wastewater pollution, whilst also providing a financial opportunity to produce products such as shellfish (oysters and mussels), marine plants (seaweed), and horticulture/aquaponics systems for vegetables.

This method is currently not utilised in Australian prawn farming operations but is used in a number of other aquaculture industries around the world, presenting opportunities to reduce their carbon footprint, and utilise waste to generate alternative sources of income (if feasible). This could be made possible by internally operating the IMTA system, or through leasing the surrounding area and providing the nutrient output for the lease owner to operate their own farm or system.

Please note, an in-depth feasibility study would be required to ensure this is economically viable for prawn farmers.

5.4.2 Waste and nutrient output management

5.4.2.1 Anaerobic digesters

Anaerobic digestors (AD) convert organic waste from aquaculture, into biogas (a renewable energy source), and digestate, which can be used for horticulture, organic fertiliser, etc. Typically used in agriculture and wastewater industries, AD may be a viable solution to utilise waste produced on prawn farms.

AD mitigates GHG emissions through the production of renewable biogas which can be used to substitute fossil fuel throughout prawn farming operations. AD also produces carbon and nitrogen-rich digestates that help to store organic carbon in soils. The use of nitrogen-rich digestate on agricultural soils helps to avoid GHG emissions related to production, distribution, and land application of synthetic nitrogen mineral fertiliser.

There has been limited research[20] on the different effectiveness of AD of freshwater, brackish, and saline wastewater from RAS facilities and co-digestion of seafood by-products and has shown promising results but with considerable operational issues. Opportunities for utilising the captured biomolecules and nutrients through microbial treatment, aquaponics, and microalgae (Figure 5-2) are all viable options. Furthermore, the nutrients can be converted into biogas or digestate for a range uses (Figure 5-3). However, this approach requires significant R&D to identify the feasibility of this technology with prawn farm operations. AD has not been utilised in prawn farming as such but has been used by abroad in fish RAS's, such as Cermaq[21]a Norwegian salmon aquaculture company which has successfully implemented a full-scale anaerobic digestor to treat the saline sludge from their salmon fry farms[22], displaying its viability with saltwater aquaculture.

[20]Choudhury, A. (2022). Anaerobic digestion challenges and resource recovery opportunities from land-based aquaculture waste and seafood processing byproducts: A review. *Anaerobic digestion challenges and resource recovery opportunities from land-based aquaculture waste and seafood processing byproducts: A review, 354*(127144).

[21] See: http://magazine.hatcheryinternational.com/publication/

[22] Lobanov, V., De Vrieze, J., & Joyce, A. (2023). Simultaneous biomethane production and nutrient remineralization from aquaculture solids. Aquacultural Engineering, 101, 102328. https://doi.org/10.1016/j.aquaeng.2023.102328

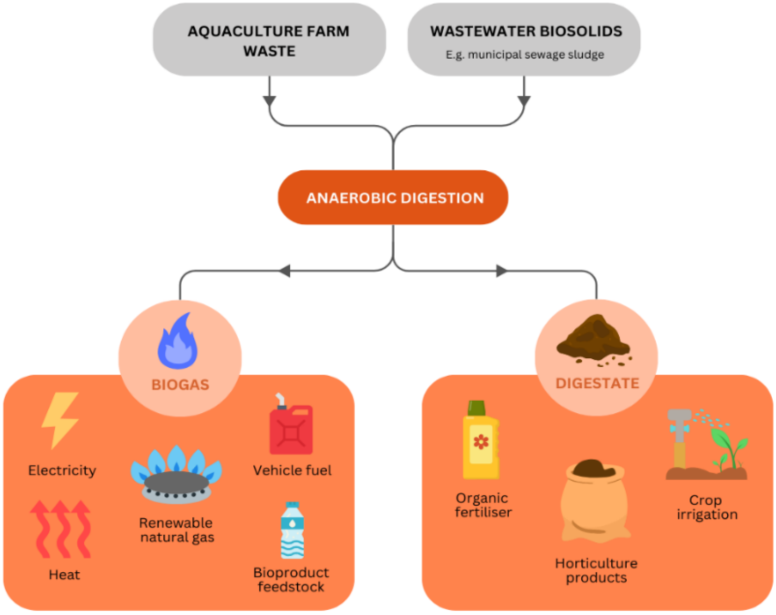

Figure 5-2 The potential uses for biomolecules from AD

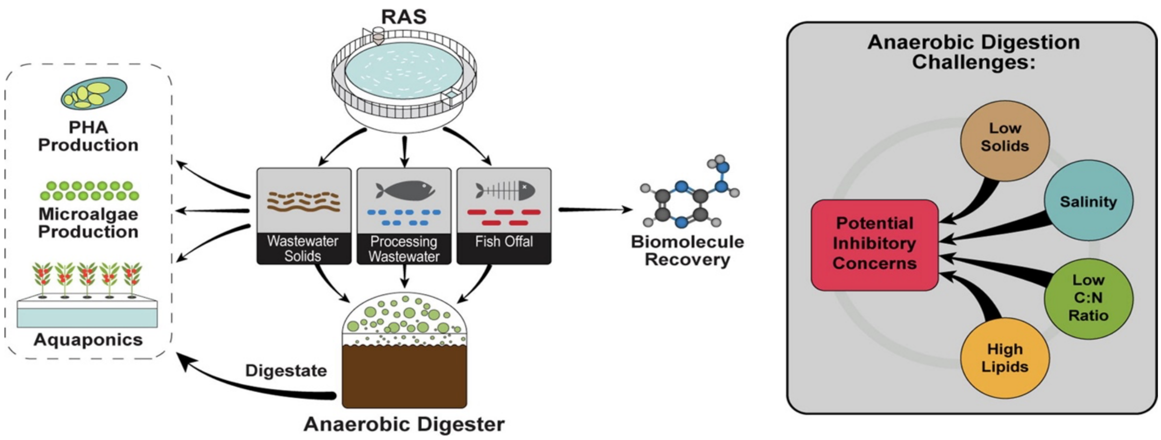

Figure 5-3 Aquaculture uses from AD

5.5 Supply chain

Supply chain emissions in prawn farming are derived from transport type, distance, process method, and storage. The emissions are relatively low compared to other contributors to prawn farmers carbon footprint, but still a contributor, nonetheless. The opportunities to limit supply chain emissions are in fact limited, as they are typically emissions contributed by another company. Firstly, it is vital that farms measure and report all carbon emissions derived from the supply chain, to allow for making informed decisions around reductions, etc.

There are two key options for farmers:

1. Offset supply chain/transport emissions; and

2. Choosing transport companies with carbon reduction goals.

5.5.1 Transport

Choosing sustainable companies along the supply chain will help mitigate scope 3 emissions for farmers. Alternatively, prawn farmers could impose an industry-wide initiative of lowered supply chain emissions for transport companies to meet to align with their sustainability objectives (e.g., transport companies need to reduce 20% of their emissions by 2030). This encourages positive change along the supply chain and furthers the emission reductions across different industries.

With plans of increased prawn production in the future, we believe this is an important step for the prawn farming industry.

5.5.2 Refrigeration

Seafood relies on a high integrity cold chain to deliver quality product to consumers. This chain begins at the point of capture or harvest and must continue uninterrupted until the point of consumption. Refrigeration leaks may be small but due to their high global warming impact, they can be a high contributor to prawn farmers carbon footprint.

Significant emissions can arise from the refrigerant leaks in cold chains[23]. Fugitive refrigerant loss is an active GHG contributor within the aquaculture sector with high global warming impacts. These proportions represent large GHG impacts for prawn farmers operating with large blast freezing requirements. In addition, refrigerant gases used in the aquaculture sectors which are lost from land-based chilling/freezer units to the atmosphere (Scope 1 direct emissions) and have high GWPs, are not being allocated to the F&A sector and included in the estimates/reporting. Our estimates based on reported and anecdotal data indicate that direct refrigerant losses could constitute 3% of the total carbon footprint of the fisheries sector. They appear to be much less significant for the Aquaculture sector but are still identified as a key contributor to the farms carbon footprint.

5.5.2.1 Maintenance schedule and routine checks

Developing and implementing an effective maintenance schedule that involves regular cleaning of coils, evaporators, and condensers will ensure that P&E operates more efficiently, reducing the energy needed for cooling and lowering emissions. Even small refrigerant leaks can significantly impact efficiency and can be a large contributor to prawn farmers carbon footprint. This will deliver benefits of reducing electricity usages and electricity based emissions, as well as cost savings through increased refrigeration P&E efficiency.

5.6 Carbon offsets

Achieving emissions reductions solely through energy efficiency actions might prove insufficient. In such cases, carbon offsets offer a valuable solution. A popular method to counterbalance GHG emissions is by financially supporting organisations to offset these emissions. For instance, by planting trees to absorb the emitted CO_2. Some organisations providing this carbon offset service include, but are certainly not limited to:

- GreenFleet (non-profit) - Approximately $18/tonne of CO_2 offset.
- Carbon Neutral (non-profit) - Offers multiple project options for investment, and the cost per tonne of CO_2 offset varies across projects.

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[23] Ulf Winther, F. Z. (2009). Carbon footprint and energy use of Norwegian seafood products. *SINTEF Fisheries and Aquaculture*.

  - Biodiverse Reforestation Carbon Offsets, Australia - $37.40/tonne (incl GST)
  - A number of international carbon offsets (https://carbonneutral.com.au/buy/#carbon-offset)
- Canopy Blue – Kelp reforestation credits. Approximately $15.50/tonne (excl GST).
- ClimateFriendly (company) - Approximately $25 per tonne of CO_2 offset.

It's essential to acknowledge that offsets should not serve as a long-term substitute for the initial reduction of CO_2 emissions. While offsets can be highly beneficial in the short term, aiding a business in achieving carbon neutrality during the transition towards emission reduction, the primary focus should remain on reducing emitted CO_2 in the first place.

These offsets can be pursued at enterprise level individual farms/aquaculture operations, and by the industry as a whole (led by APFA) to seek mutually beneficial offset opportunities in a cost effective manner. APFA could also work with carbon offsetting organisations to seek an industry wide carbon offsetting program that is mutually beneficial (mangrove reforestation, wetland restoration, etc.) and suitable to prawn farmers.

5.6.1 Gold Standard offsets

Carbon Offsets that are Gold Standard ensure that projects in carbon markets represent the highest levels of environmental integrity and deliver other verified benefits to both local communities and ecosystems. Established by the World Wildlife Fund (WWF), the Gold Standard certifies carbon offset projects that demonstrate carbon sequestration outcomes as well as positively impacting the economy, health, welfare and/or environment of the community where the project is located.

All Gold Standard carbon credits represent the reduction or removal of one tonne of CO_2 equivalent, plus the Sustainable Development Goals (SDG) benefits associated with the project from which they are issued. Gold Standard continues to represent the best that can be achieved in carbon markets, featuring the most stringent environmental and social safeguards, local stakeholder consultation as well as many other requirements for accreditation

There are countless carbon offsetting options across the globe, but it is essential to undertake extensive R&D before choosing and ensure that the offset is supported by the WWF and is listed as a Gold Standard offset.

5.6.2 Carbon initiative case studies

Australia's F&A sector is actively embracing ambitious carbon initiatives, aiming to achieve carbon neutrality and ultimately reach a net-zero carbon footprint by 2050. There are a number of companies within the sector that are pioneering transparent carbon footprint initiatives as a key pillar within their business operations, including but not limited to:

5.6.2.1 Case study - Tassal

Tassal Group is the largest vertically integrated seafood producer in Australia, with more than 30 years in growing salmon, prawns, and barramundi. Tassal's transfer of experience and innovation from salmon to tiger prawn and barramundi farming is a significant achievement in the aquaculture industry, with a strong commitment to sustainability and a minimal carbon footprint. Tassal are committed to reduce emissions by 50% by 2030, and net zero by 2050.

Tassal calculates and discloses Scope 1 and 2 emissions annually as a requirement under the NGERS Act 2007 (see https://www.cleanenergyregulator.gov.au/NGER), and Scope 3 emissions by conducting a detailed LCA of their salmon and prawn operations and supply chain.

Tassal identified that feed was their biggest contributor to their carbon footprint and is actively reducing their FCR and engaging in R&D to identify lower footprint alternatives, such as "deforestation free soy" (ProTerra certified since 2016).

5.6.2.2 Case study - Harvest Road Oceans

Harvest Road Oceans (HRO) have certified their mussel, akoya and rock oyster products as carbon neutral with the 'Climate Active' Carbon Neutral Program. These are extensively achieved through a number of emission reduction and offset initiatives, including:

- Reduction in fuel consumption
- Reducing local freight, staff travel and boat movements through integrated developments at the Albany shore base akoya and oyster production, and
- Investment in more efficient oyster handling technology, reducing vessel time.

HRO also purchases offsets with the Gold Standard Yarra Yarra Biodiversity Corridor project in Western Australia's wheatbelt.

5.6.2.3 Case study – Austral Fisheries Pty Ltd

Austral Fisheries is one of Australia's largest vertically integrated commercial fishing companies. Austral catches primarily prawns fished in Australia's Northern Prawn Fishery and Glacier 51 Toothfish™ from the Southern Ocean. Austral Fisheries are pioneers within this carbon space within the F&A sector.

Austral contribute a significant amount of CO_2 into the atmosphere each year as a part of their operations, the majority of which comes from diesel, refrigeration, and transport. As a result, Austral has planned to fully offset these emissions by planting various species of trees within the Yarra Yarra Biodiversity Corridor Gold Standard project being undertaken by Carbon Neutral Pty Ltd. This project is part of nearly 14,000 hectares that has been revegetated and will capture an estimated 1.925 million tonnes of carbon over the next 50 years. Austral plants over 220,000 mixed native species to offset its Scope 1, 2 and 3 emissions.

Further to this, Austral became the first company to purchase Canopy Blue's Reforestation Credits, offsetting carbon emissions under Climate Active program. Canopy Blue advocates kelp reforestation as a way to restore the health of marine ecosystems and combat climate change. Kelp forests are important carbon sinks, absorbing and storing large amounts of carbon dioxide from the atmosphere, whilst providing a critical habitat for marine species and supporting fisheries.

Outside of offsets, Austral has built a new vessel, the 'Cape Arkona', and has planned to build another, the 'Austral Odyssey'. These vessels contain advanced energy-saving hybrid propulsion systems featuring an integrated load shaving battery package and 2-step gear box, which Austral Fisheries says will curb emissions and further improve fuel efficiency. The design also includes increased tank capacity to accommodate the potential for future less energy-dense renewable fuels, such as methanol.

6 ROADBLOCKS & CHALLENGES TO REDUCE CARBON FOOTPRINT

Australian prawn farming GHG emissions are derived from the combination of the following components: electricity (44%); feed (24%); aquatic N_2O (13%); refrigerant leaks (13%); liquid fuels (4%); and transport (1%).

In the absence of an imposed target commitment, a carbon footprint reduction strategy should aim at reconciling profitability and emission reduction. Roadblocks on this path range from data readiness to technological barriers and regulatory environment all to be considered from a cost/ benefit or cost-effectiveness perspective. As seen in Figure 6-2, CO_2 mitigation is a cost, but has a potential to provide increased prices and profitability for farmers.

6.1 Priorities for farmers

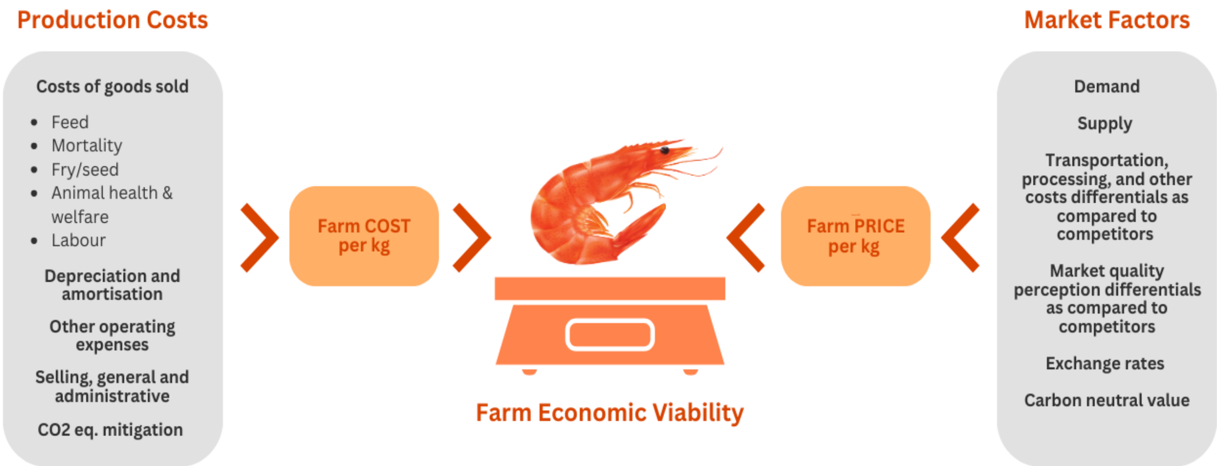

Figure 6-2 Factors for prawn farmers profitability

A significant risk stemmed from the possibility of operators prioritising carbon emissions relatively lower compared to their other business objectives. Aligning environmental sustainability goals with the core business priorities of these operators was identified as essential to mitigate this risk effectively. Additionally, a prevailing perception within the industry was that carbon accounting necessitated a high level of technical expertise and could be time-consuming, presenting a barrier to adoption. Addressing this perception and making the process more accessible to individuals with varying technical proficiencies was identified as a key strategy.

6.2 Cost of assessment

The cost of a carbon assessment can range from a few minutes online to over $50,000 based on scope, data accessibility, and frequency. This kind of investment may not be financially viable for smaller farms hence presenting a significant roadblock for these operators. Assessment is the first step towards reducing on farm emissions and overall carbon footprint, therefor without financial assistance, some small scale farms will find it unaffordable.

Measuring accurately Scope 1, 2 and 3 emissions to set-up a decarbonisation strategy requires external expertise and independence as well as internal resources which can significantly increase cost in the absence of a robust information system. The assessment process is not limited to an accounting desktop exercise but require behind-the-meter (kWh rather than electricity bill) information, asset registry (particularly for refrigerants) and employee survey which can be tedious and time consuming especially for small and medium enterprise.

Once reduction targets have been set, offsetting emissions requires yearly assessments/audits which become recurring expenses.

6.3 Uncertain financial benefits

Recent studies demonstrated that country of origin and eco-labelling both delivered Willingness To Pay (WTP) a premium for seafood. Research indicates premium ranges from 5% to over 50%, is higher for wild-caught vs farmed seafood and increases with higher value species. It must be added that all market studies and surveys focused exclusively on MSC and ASC certified seafood and there is significant uncertainty as to whether these markups are passed on to fishers/ farmers. Nothing could be found on carbon neutral seafood impact on price.

6.4 Productivity constraints

The prawn farming industry is a generally mature and operates under high productivity constraints in Australia because of high labour cost. Feed and electricity are core inputs which drive productivity but also account for over 80% of prawn aquaculture emissions. The prospect of reducing those inputs is limited to their type and origin, which largely rely on the location of the farms and feed manufacturers.

6.5 Willingness to collaborate

The opportunities to purchase “green” feed and energy are limited and will require alignment and concerted efforts to reach critical mass and increase bargaining power both with suppliers and the regulator. Further transparency from the players and namely about actual feed carbon footprint is needed to provide an accurate impact rather than offset driven carbon neutrality claims.

Unlike for remote aquaculture sites where cost of transport of fuel and generator inefficiencies and maintenance to generate electricity provides a significant incentive to invest in renewable energy, access to the grid is often the most cost-efficient solution for operators of all sizes. Only large scale and/ or allied farmers will be able to cost-effectively switch to renewables and step-away from fossil fuel grid electricity economically.

6.6 Regulatory environment

The recent Eco Markets Australia-Reef Credit approval of PacificBio/RegenAqua as a way to financially support the reduction of nutrient and or sediments run-off is promising. The legislation around Blue Carbon credits remains confusing and limited to wetland restoration, presenting a roadblock to development. The prospect of a biodiversity credit remains uncertain whereas aquaculture could enable nature-based bio-filtration solutions with multiple co-benefits to ecosystems.

In addition, the current regulation preventing multi-species aquaculture licence and outlining incompatibility with marine protected areas appears inadequate and counterproductive.

6.7 Knowledge gaps and offset trap

Nature-based solutions, bioremediation, co-culture and IMTA could all demonstrate co-benefits to prawn farmers, but the viability and value is widely unknown.

Of all the roadblocks and challenges to be considered, the most obvious and immediate may be the fact that with an 8.7 – 12.7 kg CO_2-e per kg of produced prawns in Australia, it would only cost 30 to 45 cents per kg of produced prawns, to offset its emissions using $30/tonne credits or a fraction of a percent of selling price.

The Australian aquaculture industry competitiveness and profitability are productivity driven because of a relatively high cost of labour. Over 90% of prawn farming GHG emissions in Australia are derived from electricity and feed inputs, diesel, refrigerants leakage and NO_X production and release.

6.8 Cost-effectiveness vs value adding

Perhaps the most important challenge to overcome is the cost-effectiveness of emission offsetting. Even with a carbon footprint 8.7 – 12.7 kg CO_2-e per kg of produced prawns, the cost to offset would be a fraction of a percent of the selling price, making it a very tempting value proposition if the right carbon offset program is chosen (e.g., Gold Standard).

Overall, the level of efficiency of the Australian prawn industry is limiting the prospect of emission reduction to either costly emerging technologies and/ or relatively complex nature-based solutions. Nature-based solutions require scientific validation but may deliver multiple co-benefits and significantly improve the image of the sector/ social license to operate and superior prices provided taste and nutritional value are there.

7 RESEARCH PRIORITY AREAS TO ENABLE INDUSTRY TO REDUCE ITS CARBON FOOTPRINT

7.1 Electricity reduction

Electricity is the highest GHG emission contributor as well as incurring significant costs. Reducing electricity usage on-farm is the key research priority to both reduce both costs and overall carbon footprint.

7.1.1 Renewable sources

There is a need for QLD to develop their renewable sector to provide alternatives to fossil fuels (primarily coal) and reduce prawn farmers carbon footprint. QLD has a renewable target to align with 50% reductio in emissions by 2030.

A research priority is needed to first identify renewable opportunities in the state, undertake a feasibility assessment of all types (solar, wind, etc.), and implementation/transition to renewable sources.

7.1.1.1 Collective renewable power generation

Due to the significant capital investment required for farms to construct their own renewable power generation to support their farm, farmers and APFA must consider the possibility of collective renewable power generation. Close proximity farms need to collectively work together to provide a renewable option for all farms. This could include a collective renewable grid where farmers equally contribute (relative to production and need) to provide renewable opportunities for prawn farmers within the same region.

Note that this opportunity is only viable for close proximity prawn farms.

7.1.1.2 Aquaculture Development Areas (ADA's)

Prawn farmers need to investigate the possibility for their own renewable power generation in these ADA's. As mentioned earlier in the report, this will provide financial assistance for prawn farmers to potentially reduce their carbon footprints.

7.2 Cost benefit analysis & cost effectiveness

For many businesses, any method of reducing carbon needs to be cost effective, therefore displaying the need to undertake individual feasibility assessments prior to any implementation. Reducing GHG emissions needs to be pursued through methods that are both economically viable (e.g., concentrating on strategies that achieve the desired reduction at minimal expense) and socially advantageous (e.g., cutting emissions until the costs of mitigation match the societal benefits of reducing emissions). Marginal abatement cost curves, known as "MACCs," offer a means of assessing the cost-efficiency of possible mitigation approaches and have been extensively employed in formulating agricultural mitigation policies.[24].

The key steps in this process are as follows:

1. Identification and selection of mitigation measures;
2. Review the potential effects of the measures;
3. Calculation of the emissions and farm profit for a farm (or farms) under baseline conditions;
4. Calculation of the emissions and farm profit for a farm (or farms) with each measure; and
5. Based on 3 and 4, calculation of the change in emissions and profits arising from each measure and calculation of the cost-effectiveness (CE) of each measure.

For a given measure, optimal pollution abatement occurs where the marginal cost of abatement equals the marginal benefit, i.e. where the two curves cross (Figure 7-1).

Farmers need to identify if there is a benefit, through pilot study and in-depth cost benefit analysis's identifying the potential cost benefits of eco labelling, carbon neutrality labelling, etc. This is the key overarching research priority.

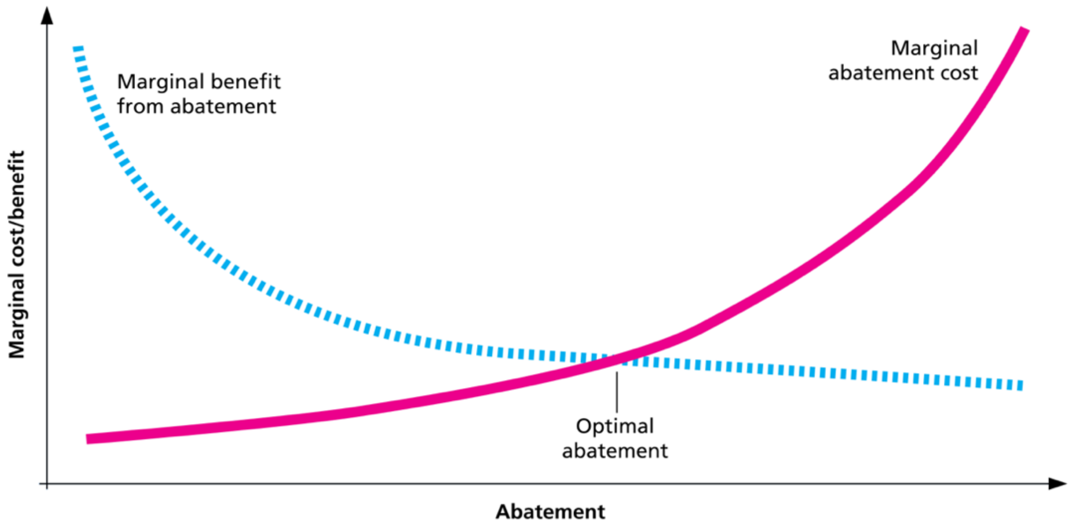

Figure 7-1 Marginal abatement costs and benefits[25]

7.3 Annual carbon footprint audits and benchmarking

Developing standardised metrics for accurate carbon footprint reporting and benchmarking will allow prawn farmers to actively assess their carbon footprint. The objective of this research priority is to establish standardised methodologies, metrics, and reporting protocols specifically designed for prawn farming operations to accurately measure, report, and benchmark their annual carbon footprint.

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[24] MacLeod, M. H.-U.-R. (2019). Quantifying and mitigating greenhouse gas emissions from global aquaculture. *FAO Fisheries and Aquaculture Technical Paper No. 626*, 49.

[25] Bennett, Jeff W. "Pearce, D. W., and R. K. Turner. *Economics of Natural Resources and the Environment*. Baltimore MD: Johns Hopkins University Press, 1990, 378 Pp.Paper." *American Journal of Agricultural Economics* 73, no. 1 (February 1991): 227–28. https://doi.org/10.2307/1242904.

7.4 Feed

Feed is a key research priority that needs to be continually developed. Lowering farms FCR is key to lowering both their carbon footprint and costs, being significantly beneficial to business. This can be sought out by a number of key research priorities surrounding alternative feed inputs, technology, genetic enhancement, and a range of other RD&E opportunities. This also limits feed and nutrient waste, again having a positive impact on the farms carbon footprint.

This research is typically lead by feed companies, but prawn farms can also undertake their own research or aid feed companies in their research.

7.4.1 Technology

Newly developed acoustic feed technology, including as the AQ1 automatic feeder, have proven to increase feed efficiency and reduce waste. This type of technology is really only beneficial in large scale/high stocking density farms. APFA needs to place a key research priority in encouraging this type of technology across farms to lower the industries carbon footprint, as well as developing similar technology for small scale/low stocking density farms.

7.4.2 Breeding and genetic enhancement

Breeding and genetical enhancement for improved FCR, reducing feed and improving physical performance, reducing carbon footprint derived from intensive feed. There has been some research undertaken in Asia on freshwater prawns (*Macrobrachium rosenbergii)* on selective breeding approaches to improve productivity and feed efficiency[26].

7.5 Blue carbon sequestration and abatement opportunities

7.5.1 Blue carbon sequestration

Australian prawn farmers should consider developing a key research priority around developing their own blue carbon sequestration program to mitigate/offset their carbon impacts. A number of universities and research agencies with capability in blue carbon can fund or be part of their own blue carbon program, such as wetland/mangrove reforestation.

7.5.2 Reforestation

APFA and prawn farmers are concerned about carbon reduction and environmental mitigation, a research priority should be developed for reforestation initiatives. This involves actively identifying and pursuing reforestation opportunities in the vicinity of prawn farming sites. Furthermore, exploring the effective utilisation of excess nutrients, for reforestation purposes is crucial. Seeking governmental investment and support for reforestation projects will also be imperative to ensure the success and scale of these initiatives within prawn farming practices.

7.5.3 Anaerobic digestors

Anaerobic digestors are typically not associated with aquaculture, but present a viable opportunity to utilise waste for other uses such as biofuel, horticulture, etc. There needs to be a RD&E into this technology in terms of carbon reduction, and an investigation of the economic viability and potential.

[26] Nguyen, N. H. (2015). Genetic improvement for important farmed aquaculture species with a reference to carp, tilapia and prawns in Asia: achievements, lessons and challenges . *Fish and Fisheries*.

7.6 Carbon offsets

By utilising the carbon offset opportunities list in section 6, investigate the ‘Gold Standard’ carbon offsetting opportunities and examples from carbon neutral companies in QLD and throughout Australia, that are best suited to prawn farmers. These carbon offsets need to align with either the business/farm or APFA’s strategic goals.

Future research needs to include a collaboration with Blue Carbon Labs, Nature Positive and/or Carbon Neutral to develop a carbon offset opportunity in QLD tailored towards prawn farmers (e.g., wetlands/coastal ecosystem reforestation, etc.).

7.6.1 Carbon offset or “green wash”

To validate genuine commitment to sustainability, prawn farmers will need to work towards achieving formal certification as a Carbon Neutral entity under the Australian Government Carbon Neutral Program. The assessment, aligning with the Australian National Carbon Offset Standard (NCOS), needs to be then independently audited and receive official approval from the Australian Government.

8 THE IMPACT OF SUSTAINABILITY AND CARBON NEUTRALITY ON PRAWN MARKETABILITY

Verifiable sustainability and carbon neutrality claims can have a significant positive impact on the marketability of farmed prawn products. In recent years, the growing awareness of consumers has led to a rising demand for responsibly sourced seafood[27]. This demand has resulted in the development of certification and ecolabelling programmes which promote responsible aquaculture practices These programmes assess and certify performance of aquaculture farms against a series of criteria including:

- Environmental responsibility
- Animal health and welfare
- Food safety
- Social accountability

Global aquaculture accreditation schemes such as Global Seafood Alliance (GSA) - Best Aquaculture Practices (BAP) and Aquaculture Stewardship Council (ASC) are currently moving to include energy use/carbon footprints within their assessment frameworks. ASC currently ensure farms are closely monitoring energy use and an upgraded ASC Shrimp Standard likely to require farms to be working to reduce emissions. BAP are developing the Climate Action and Sourcing Vanguard Standard for feed mills, farms and processing plants.

8.1 Advantages

8.1.1 Consumer demand

Sustainable, emissions reduction and carbon neutral claims can create a competitive advantage for farmed prawn products by appealing to a growing sector of environmentally conscious consumers. These consumers demonstrate a preference for products which contribute to the greater good of the planet and are willing to pay for the price premiums to which they are attached. As consumer awareness grows around sustainability-related issues, so too does the demand for responsibly sourced seafood. This creates a self-perpetuating cycle whereby sustainable production is incentivised by access to increasing consumer demand[28].

8.1.2 Price premium

One of the greatest benefits of sustainability claims is the price premiums which they command. These price premiums signal a return on investment in sustainable production, thereby providing an incentive for producers to adapt their production methods. A prerequisite for price premiums at the producer level is a readiness to pay for sustainable seafood over other standard products. Evidence

[27] Van Putten et al. (2020). Shifting focus: the impacts of sustainable seafood certification. *PLOS ONE 15*(6). https://shorturl.at/jw259.
[28] Roheim et al. (2018). Evolution and future of the sustainable seafood market. *Nature Sustainability 1.* https://shorturl.at/bhCSY.

suggests that this readiness exists, and consumers are willing to pay up to 10% higher for sustainably farmed seafood[29].

8.1.3 Willingness To Pay (WTP)

WTP a premium is often a function of consumer perceived value. Quality (taste and freshness) and rarity (limited availability and/ or seasonality) are key drivers to establish a pecking order amongst seafood types and species.

Main driver of premium is local origin followed by eco-labelling which varies significantly by species and countries (disclosure now compulsory for hospitality in addition to supermarkets and retailers). WTP on ecolabel has stronger impact for wild caught and can reach 20-30% premium[30]. Most studies available were conducted for MSC/ ASC certified products which contain a carbon section but cover elements.

8.1.3.1 *Case study: Certified vs uncertified octopus from Asturias (Spain)*[31]

Since 2016, the artisanal fleet to fish common octopus of Navia-Porcía (Asturias, Spain) is certified by the Marine Stewardship Council (MSC), being the first octopus fishery certified by MSC in the world. In this analysis, the difference-in-difference (DiD) method was applied to a panel of prices and quantities of common octopus sold at ports in the Spanish region of Asturias from 2010 to 2019. The results confirm a price premium, ranging between 15.2% and 24.6% over the price of uncertified octopus, paid to Asturian fishers who harvest and sell the MSC-certified product.

8.1.4 Improved access to markets

Market access is one of the more commonly realised and identifiable drivers for aquaculture producers to pursue sustainability/carbon neutrality claims[32]. By verifying the sustainability of their products, producers secure access to the growing market for responsibly sourced products. It is important to note that there is significant variation in the economic benefits provided by market access. This is due to several factors including the demand for sustainably sourced seafood, the availability and abundance of competing products in the market and trading conditions.

8.1.5 Improved public image

While the majority of research indicates that the main motivation for sustainability/carbon neutrality claims are financial benefits (e.g., access to markets and price premiums), the strengthening of a company's public image also plays a key role. This is particularly true for the aquaculture industry which has suffered from a lack of firm knowledge and a high degree of uncertainty about the environmental consequences of production. The ability for aquaculture companies to respond to public pressure for more sustainable production is key to demonstrating

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[29] Asche et al. (2021). The value of responsibly farmed fish: a hedonic price study of ASC-certified whitefish. *Ecological Economics* 188. https://shorturl.at/nEMWY.
[30] Vitale, S., Giosuè, C., Biondo, F., Bono, G. B., Sprovieri, M., & Attanasio, M. (2017). Are people willing to pay for eco-labeled wild seafood? an overview. *European Journal of Sustainable Development*, *6*(3). https://doi.org/10.14207/ejsd.2017.v6n3p20
[31] Sánchez, J. L. (2020). Evidence of price premium for MSC-certified products at fishers' level: The case of the artisanal fleet of common octopus from Asturias (Spain). *Marine Policy*.
[32] Ababouch et al. (2023). Value chains and market access for aquaculture products. *Journal of the World Aquaculture Society 54*(2). https://shorturl.at/hpxBY.

their social and environmental legitimacy[33]. This is vital to strengthening a company's public image and increasing social support and acceptance.

8.1.6 Social license to operate

Increasingly, social license to operate (SLO) has become integrated into aquaculture policies to help generate societal support of the industry. By addressing the social relationship between industry and community, SLO recognises the significant power wielded by the public. This power is demonstrated in their ability to create delays in operation, pressure governing bodies into tightening regulations, and influence consumer purchasing preference – all of which equate to significant economic costs. By securing and maintaining community approval, companies are less likely to encounter resistance from the public. This approval can be gained through verifiable sustainability and carbon neutrality claims[34]. By consistently demonstrating a commitment to these claims, producers can build a strong and positive reputation.

8.1.6.1 Case Study – the Omarsa Group: a sustainability trendsetter in prawn farming

Omarsa is Ecuador's second largest shrimp exporter, exporting to 45 countries and employing over 7000 people. Through their ASC certification, they have demonstrated a solid, long-term commitment to environmental (partly through carbon reduction) and social responsibility. Of note, is their investment in mangrove rehabilitation. Through time, they have restored degraded mangroves on the farms they have acquired to improve their carbon footprint and provide benefit to the ecosystem. This has had a number of benefits including the promotion of biodiversity conservation, carbon footprint reduction and the recreation of essential habitat. By pursuing sustainable practices, they continues to satisfy consumers and anticipate customer needs in accordance with the requirements of the international market. This has enabled significant growth within the company.

8.1.6.2 Case Study – Quoc Viet: the benefits of certification on shrimp farming operations

Quoc Viet was Asia's first shrimp farm to achieve ASC certification in 2015. This offered a number of positive economic outcomes including price premiums and access to new markets (particularly across Europe where there is a high demand from responsibly sourced seafood). It also improved prawn farming practices through improved management and monitoring techniques, the utilisation of appropriate stocking densities, and enhanced biosecurity approaches.

8.2 Cost of reducing carbon footprint

Whilst seemingly advantageous, there are a number of costs that must be considered when reducing the carbon footprint of farmed prawn products. Typically, these costs are attributed to the operational changes required to implement environmentally responsible farming practices and achieve compliance with standards. They include:

- Investments into costly technologies, equipment, and methodologies.
- Purchasing carbon offsets to compensate for emissions that cannot be eliminated entirely.
- Costs involved in achieving and maintaining sustainability certifications.

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[33] Olsen et al. (2021). Certifying the public image? Reputational gains of certification in Norwegian salmon aquaculture. *Aquaculture 542.* https://shorturl.at/ftBM1.

[34] Ogier, E.M. & Brooks, K. (2016). *License to engage: Gaining and retaining your social license in the seafood industry. A Handbook of available knowledge and tools for effective seafood industry engagement with communities. FRDC.* https://shorturl.at/acP27.

- Investments into marketing and consumer education to communicate commitment to sustainability and carbon neutrality.

Beyond the operational costs, there is also a risk that new procedures may negatively affect productivity. Producers may only be able to bear such costs provided there is strong consumer demand for sustainably farmed prawns or there is a regulatory requirement imposed upon them. In the absence of this demand or conditions, the effort to reduce the carbon footprint of Australian farmed prawns serves only to elevate costs, therefore adversely affecting profitability.

8.2.1 Cost-Benefit Analysis

As the market for sustainable aquaculture products increases, farmers must determine whether the pursuit towards sustainability is worth the initial cost burden. Producers may benefit from undertaking cost-benefit analyses prior to implementing a sustainability improvement. These analyses serve as a decision-making tool to help estimate the actions and associated costs required to achieve compliance with sustainability standards.

9 CONCLUSION

9.1 Objectives

The project had six key objectives:

1. Report on the carbon balance of prawn production – benchmark the Australian Prawn Farming industry;
2. Identify any differences between large- and small-scale prawn production/farms;
3. Identify pathways and opportunities to reduce carbon footprint – enterprise and industry level (including carbon sequestration and blue carbon potential);
4. Identify roadblocks and challenges to reduce carbon footprint – enterprise and industry level.
5. Identify research priority areas to enable industry to reduce its carbon footprint; and
6. Report on the impact of sustainability and carbon neutrality claims/certification on prawn marketability.

Due to limited small-scale farmer contribution, we were unable to identify any differences between large- and small-scale prawn production/farms. However we recommended this is revisited at a quieter period for prawn farmers.

9.2 Drivers for reporting GHG emissions

Current drivers for reporting energy consumption and GHG emissions within the Australian F&A sectors include the following aspects:

- Increased scrutiny by stakeholders, including government bodies, non-governmental organisations (NGOs), shareholders, and consumers.
- Establishing GHG baseline measurements for the F&A sectors, against which future performance can be assessed and potentially compared with other food production sectors.
- An imperative for the F&A sectors to differentiate emissions within the agriculture sector and provide precise, detailed, and distinct assessments of their GHG contributions within the 'Agriculture' category. Currently, this sector is aggregated, making individual contributions less discernible.
- The demand for companies, small and medium-sized enterprises (SMEs), and individuals to possess the capability to quantify their energy consumption and GHG emissions before embarking on mitigation strategies.
- The development of more extensive and higher-quality data which may facilitate novel opportunities within the F&A sector.

9.3 Updated Carbon Footprint

"Pathways and opportunities to reduce the carbon footprint of the Australian prawn farming industry" was imperative to providing APFA with an updated carbon footprint of their operations. Our results compared to a previous study[35] showed a reduction from 15.2 kg CO_2-e to 9.68 kg CO_2-e per kg of produced prawns. This is largely attributed increase on farm efficiency, a reduction in QLD's

[35] FRDC No 2020/089. Bell, Robert A., Blueshift Consulting 2022, Energy use and carbon emissions assessments in the Australian fishing and aquaculture sectors: Audit, self-assessment, and guidance tools for footprint reduction, Canberra, Australia, (April).

EF through decreased reliance on coal power (increased renewables), and that there were no small production farms (<100t) surveyed as a part of this study.

9.4 Key carbon contributors

Prawn farms carbon footprints were driven significantly by Scope 2 emissions (purchased electricity) and Scope 3 emissions (feed). Other contributors include refrigeration leaks, liquid fuels used on farm, and off-farm transport.

Table 7 Weighted average GHG emissions from prawn farm responses (kg CO_2-e per kg of produced prawns)

	Scope 1		Scope 2	Scope 3		Total
Liquid fuels	Refrigerants	Aquatic N2O	Electricity	Feed	Transport	
0.41	1.24	1.30	4.25	2.36	0.12	**9.68**

Scope 1 emissions (liquid fuel, refrigerant and aquatic N_2O) are estimated at 2.05 - 4.84 kg CO_2-e per kg of produced prawns, with a weighted average of 2.95 CO_2-e per kg. This represents 30.5%.

Scope 2 emissions (purchased electricity) are estimated at 3.4 - 7.8 kg CO_2-e per kg of produced prawns with a weighted average of 4.25 kg CO_2-e per kg. This represents 43.9% of a typical Australian prawn farm's carbon footprint.

Scope 3 emissions (feed) are estimated at 2.27 - 2.76 kg CO_2-e per kg of produced prawns for Australian farms, with a weighted average of 2.48 kg CO_2-e per kg. This represents 25.6% of a typical Australian prawn farm's carbon footprint.

9.5 Carbon reduction opportunities

Reducing carbon emissions stemming from electricity usage emerges as a crucial avenue for improving sustainability and lowering operational costs within the prawn farming industry. With electricity accounting for a significant portion of the carbon footprint (44%), transitioning to renewable energy sources presents a dual opportunity for emission reduction and cost savings. Queensland's 2030 target of achieving 50% renewable energy offers a supportive framework for such transitions, with numerous initiatives and investments aimed at expanding renewable energy infrastructure across the state. Prerequisite to this transition is a comprehensive understanding of available renewable energy options and their viability, with solar power emerging as the most accessible and widely available option.

Collaborative approaches among prawn farmers, such as collective renewable energy projects, present additional opportunities to mitigate costs and emissions collectively. The Queensland government's support for renewable energy initiatives, coupled with its investment in aquaculture development areas, underscores the potential for synergy between sustainable energy transitions and industry growth. However, realizing these opportunities necessitates careful planning, collaboration, and potentially significant investment, highlighting the importance of strategic alignment between industry stakeholders and government priorities.

Energy audits for prawn farms, facilitated by programs like the ecoBiz program in QLD, are great opportunities for individual prawn farmers to reduce their carbon footprint as well as costs. These audits provide invaluable insights into potential energy-saving measures, offering opportunities to decrease energy consumption, lower costs, and reduce carbon emissions. For instance, Crowley Aquaculture Farm's case study demonstrates how implementing audit recommendations, such as restructuring tariffs and adopting solar PV systems, can lead to substantial energy and cost savings, illustrating the tangible benefits of such initiatives.

Furthermore, the discussion underscores the critical role of energy-efficient plant and equipment, particularly aerators, which represent a significant portion of energy usage on prawn farms. By adopting innovative technologies that automate aerator operations and integrate with renewable energy sources, farmers can optimise energy usage while maintaining optimal conditions for prawn growth. Additionally, the section highlights the importance of sustainable feed practices and blue carbon sequestration in mitigating the carbon footprint of prawn farming operations. These initiatives not only contribute to environmental sustainability but also offer opportunities for farmers to enhance their operational efficiency and reduce their overall carbon emissions, aligning with broader efforts to combat climate change.

9.6 Roadblocks to reducing prawn farmers carbon footprint

With over 90% of emissions originating from electricity, feed, refrigerant leaks, processing, and fuel, it is evident that targeted mitigation strategies are essential to reduce the sector's carbon footprint. However, the absence of mandated emission targets necessitates a nuanced approach that balances emission reduction with profitability, taking into account factors such as data readiness, technological barriers, and regulatory environments.

Alignment of environmental sustainability goals with core business priorities is paramount, alongside efforts to simplify carbon accounting processes to facilitate wider adoption among industry stakeholders. Furthermore, the significant cost associated with carbon assessments poses a challenge, particularly for smaller farms, highlighting the need for accessible and cost-effective measurement solutions. Despite these challenges, the potential for premium prices for eco-labelled seafood presents an opportunity, albeit with uncertainties surrounding carbon neutral claims. Moving forward, collaborative efforts, regulatory clarity, and further research into nature-based solutions are imperative to address knowledge gaps and enhance the industry's competitiveness and sustainability in the face of climate change.

9.7 Research priorities for prawn farmers

The prominence of electricity as the highest GHG contributor underscores the need for concerted efforts in this area. Transitioning to renewable sources presents a promising avenue, with Queensland's renewable targets offering a framework for action. Collective renewable power generation and exploration of Aquaculture Development Areas (ADAs) further signify potential pathways for industry-wide emission reduction. However, the effectiveness of emission reduction strategies must be balanced with cost considerations.

Conducting thorough cost-benefit analyses and implementing economically viable measures are paramount. Standardised metrics for carbon footprint reporting and benchmarking can facilitate informed decision-making, while advancements in feed technology and alternative protein sources offer avenues for reducing both carbon footprints and operational costs. Additionally, exploring blue carbon sequestration, reforestation initiatives, and anaerobic digesters can provide further avenues for emission mitigation.

Carbon offsetting programs such as the Gold Standard and certification under the Australian Government Carbon Neutral Program can validate sustainability commitments and provide tangible pathways toward carbon neutrality. Future research efforts should prioritise the identification and implementation of cost-effective emission reduction strategies tailored to the specific needs and challenges of the prawn farming industry.

9.8 Impact of sustainability claims on prawn marketability

Sustainability and carbon neutrality claims wield positive influence on the marketability of farmed prawn products, driven by the increasing consumer demand for responsibly sourced seafood. Certification and ecolabeling programs, such as the Global Seafood Alliance (GSA) - Best Aquaculture Practices (BAP) and Aquaculture Stewardship Council (ASC), emphasise environmental responsibility and are evolving to include energy use and carbon footprints in their assessments.

The advantages of sustainability claims include consumer demand, price premiums, willingness to pay (WTP), improved market access, enhanced public image, and social license to operate (SLO). Case studies, such as the Omarsa Group and Quoc Viet, highlight the economic benefits and reputational gains achieved through sustainability initiatives.

The costs of reducing carbon footprints should be carefully considered, encompassing investments in technology, carbon offsets, certification, and marketing. Conducting cost-benefit analyses becomes crucial for farmers to evaluate the feasibility of sustainability improvements amidst the evolving market landscape. Ultimately, while pursuing sustainability entails costs and operational changes, it also presents opportunities for market differentiation, profitability, and long-term resilience in the face of consumer preferences and regulatory trends.

10 PROJECT MATERIALS DEVELOPED

This project has developed a Microsoft Excel-based GHG Footprint Self-Assessment Tool for the prawn farming industry:

- Blueshift Aquaculture Onshore GHG Footprint Tool

The tool is available for download on the projects page of the Blueshift Consulting website (https://blueshiftconsulting.com.au/projects).

A brochure was also developed for extension of the results and key recommendations to prawn farmers.