Energy use and carbon emissions assessments in the Australian fishing and aquaculture sectors

Audit, self-assessment, and guidance tools for footprint reduction

Blueshift Consulting

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In submitting this report, the researcher has agreed to FRDC publishing this material in its edited form.

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Abbreviations

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
AES	Australian Energy Statistics
AFDF	Alaska Fisheries Development Foundation
AFF	Agriculture, Forestry & Fishing Industry Classification
AGEIS	Australian Greenhouse Emissions Information System
ANZSIC	Australia and New Zealand Standard Industrial Classification
ADO	Automotive Diesel Oil
ATO	Australian Tax Office
BIC	Business Industry Code
CE	Carbon equivalent
CER	Clean Energy Regulator
CFC	Chlorofluorocarbon
CH_4	Methane
CNG	Compressed Natural Gas
CNP	Carbon Neutral Program
CO_2	Carbon dioxide
CO_2-e	Carbon dioxide equivalent
DEE	Department of the Environment and Energy
DISER	Australian Government Department of Industry, Science, Energy & Resources
EEA	Economic Environmental Accounting
ECM	Energy Conservation Measures
EF	Emission Factor
ESG	Environmental, social and governance
EU	Energy Use
F&A	Fishing or Fisheries and Aquaculture
FRDC	Fisheries Research and Development Corporation
FTCS	Fuel Tax Credit Scheme
FVEAT	Fishing Vessel Energy Analysis Tool
GHG	Greenhouse Gas(es)
GVM	Gross vehicle mass
GVP	Gross value of production
GWP	Global Warming Potential
HFCs	Hydrofluorocarbons
IPCC	Intergovernmental Panel on Climate Change
KP	Kyoto Protocol
kt	kilotonnes
LIFE	Low Impact and Fuel Efficient
LCA	Life Cycle Assessment / Life Cycle Analysis
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LULUCF	Land Use, Land Use Change & Forestry

MDO	Marine Diesel Oil
MGO	Marine Gas Oil
NCOS	National Carbon Offset Standard
NDC	nationally determined contribution
n.e.c.	Not elsewhere classified
N_2O	Nitrous oxide
NEI	Not elsewhere indicated
NGA	National Greenhouse Accounts
NGER	The National Greenhouse and Energy Reporting Scheme
NGGI	National Greenhouse Gas Inventory
NGO	Non-Governmental Organisation
NIBES	National Inventory by Economic Sector
NPF	Northern Prawn Fishery
PFCs	Perfluorocarbons
R&D	Research and Development
RAC	Refrigeration and air conditioning
SDG	Sustainable Development Goals
SF_6	Sulphur hexafluoride
SME	Small to medium-sized enterprise
UNFCCC	United Nations Framework Convention on Climate Change
VCP	Volume caught or produced

Executive Summary

Calculating seafood's carbon footprint: The development of the first carbon footprint of Australia's fishing and aquaculture sectors could give our seafood a competitive edge when it comes to consumer preferences for low-emission proteins.

FRDC Project 2020/89 *Energy use and carbon emissions assessments in the Australian fishing & aquaculture sectors*, undertaken by Blueshift Consulting, is the first examination of the total carbon emissions of the Australian fishing and aquaculture (F&A) sectors and component seafood production industries. To date, some work had been done on energy consumption and efficiency improvements, but the carbon emissions of the Australian F&A sectors had never been calculated.

In Australia's National Greenhouse Accounts, emissions from the F&A sectors are currently included within the aggregated 'agriculture, forestry and fishing' segment. This segment is the third largest in Australia's inventory, and the 'fishing industry' data is overwhelmed within the large, aggregated datasets of these combined sectors and therefore often unintentionally overlooked.

However, measuring the carbon footprint of the F&A sectors was a complicated task that required an account of **all** the emissions generated directly and indirectly by the sectors. This included fuel burnt directly to power fishing vessels, to purchased electricity, refrigeration emissions and the emissions from services and products bought from external suppliers such as bait and aquaculture feed. The study measured the carbon emissions and energy use of Australia's largest F&A producer industries, which together constitute about 82% of Australia's domestic seafood production by gross value of production (GVP) (see Table 1). While some of the other industries that make supply chain inputs to the F&A sectors are discussed (such as aquaculture feeds and fishing bait), the project focus is on the Australian seafood primary producers.

The information is a vital step in providing a competitive advantage for seafood as a low- emissions protein. Seafood consumers are increasingly wanting to know the stories behind the products they're buying, including efforts by fishers and farmers to reduce their carbon footprint.

It also highlights how seafood production may need to adapt in the future.

What is the carbon footprint (or *fin*print…) of my product?

When fishing and aquaculture operators understand how their businesses create emissions, they can make appropriate changes to reduce both emissions and energy costs. This might include using alternative fuels, driving vehicles or vessels to conserve fuel or changing suppliers.

As an output of the project, a 'toolbox' of resources has been produced to help smaller operators begin their own journey by measuring and managing emissions. It provides a series of examples of how other companies go about measuring, managing, and marketing their emissions.

In addition, a new self-assessment tool will help operators convert their costs into a carbon number. They can then track their operations year by year and compare themselves within their sector or to other sectors.

What are GHGs and GWPs?

Greenhouse gases (**GHGs**) 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 or CO2) is the primary greenhouse gas emitted through human activities. In 2019, CO_2 accounted for about 80% of all greenhouse gas emissions from human activities.

Greenhouse gas emissions are measured as tonnes of carbon dioxide equivalence (CO_2-e) using Global Warming Potential (**GWP**) weighting factors. GWPs, developed to allow comparisons of the global warming impacts of different gases have been used for each of the six major greenhouse gases to convert them to carbon dioxide equivalents (CO_2-e). GWPs provide a common unit of measure, which allows analysts to aggregate emissions contributions from different gases (e.g. to compile a national GHG inventory) and allows policymakers to compare emissions reduction opportunities across sectors and gases.

Background

It's hard to open a piece of media today without reading, or hearing about climate change, or government, conservation and community groups calling for 'decarbonisation'. Similarly, the efforts of industry, inventors, and entrepreneurs to develop new tools for reducing energy use and decreasing greenhouse gas emissions (also broadly called 'carbon' emissions) are also receiving much attention. Within this debate, the food production sectors have been on the front-line of increasing consumer scrutiny about their sustainability and the carbon footprints of their relative products. And whilst seafood production from fishing and aquaculture has been generally regarded as having better credentials than other forms of animal protein production, these too, have faced consumer pressure.

Therefore, to remain competitive and to highlight the comparative benefits of eating seafood compared to other proteins, it behoves Australian seafood producers to start measuring and managing their emissions profiles. On the other side of the carbon accounts ledger, there are also rapidly expanding developments in 'non-fed' aquaculture – growing animals and plants without feed inputs – and the use of marine plants and particularly seaweed culture to also create 'blue carbon' sinks. Both these areas have great potential in expanding the volume and quality of low carbon, accessible food protein whilst lowering the environmental impacts of its production.

Specific drivers and needs for the project and for further information on energy use and greenhouse gas (GHG) emissions in the Australian fisheries and aquaculture sectors include:

- greatly increased **stakeholder scrutiny** on fisheries and aquaculture, and seafood products – from government, NGOs, shareholders, and consumers
- the need for **GHG baselines** for the F&A sectors, against which further performance can be measured (and potentially benchmarked against other food production sectors)
- commercial imperatives for the F&A sectors to provide clear, disaggregated, determined, and differentiated assessment of its GHG contributions within 'Agriculture' which is currently a large, aggregated sector and dataset
- a need for companies, small to medium-sized enterprises (SMEs), and individuals to be able **to measure before managing their energy use and GHG emissions**, and
- development of more and better-quality **data,** to drive **new opportunities for the F&A sectors** and to continue to underpin the **competitiveness** of seafood in **consumer protein decision-making** and food selections.

Project objectives

Specifically, the project had three principal programs and objectives:

Program 1:	Establish energy use and greenhouse gas (GHG) profile of Australian Fishing and Aquaculture sectors
Program 2:	Develop a self-assessment tool for the Australian Fishing and Aquaculture sectors - to calculate energy efficiency and GHG emissions, and
Program 3:	Develop a toolbox and examples for emissions reduction opportunities in the Fishing and Aquaculture sectors.

Methodology

The wide range of species, catching and growing methods in the Australian F&A sectors, provides a complex matrix of energy usage and subsequent GHG emissions profiles. This report provides an overview of Australia's largest fisheries (wild-catch and aquaculture) by GVP, their catch/production methods and an indication of the emissions scopes and relative importance of the emissions.

A compilation comprised of both top-down data provided in the Australian National Inventory by Industry Sector (NIBES), and bottom-up industry and anecdotal data, has enabled a summary of likely GHG emissions for the major seafood producers within the F&A sectors to be prepared, and has identified issues and opportunities to improve GHG emissions data capture for the F&A sectors.

Key findings

Key findings from this project are a snapshot profile of GHG emissions for the F&A sector in Australia and issues and opportunities for improvement in GHG data capture, estimates and reporting found during the project, along with recommendations to resolve issues and opportunities to improve.

The GHG emissions of the Australian F&A sectors as represented by the top 11 fisheries constituting 82% of all Australian seafood production (2019-20) is estimated to be approximately **1.5 million Mt CO_2-e**. This equates to an **average GHG intensity of 6.5 kg CO_2-e per kg of Australian produced seafood** from fishing and aquaculture. A summary of the results is provided in **Table 1**.

*Table 1: Greenhouse gas emissions from Australian fisheries and aquaculture (CO2-e)**

FISHERY/ SPECIES	TOTAL EMISSIONS (kt CO_2-e)	KG CO_2-e PER KG FISH PRODUCED
Sardines – wildcatch	68,066	**1.6**
Other finfish – wildcatch	280,260	**4.5**
Oysters - farmed	42,248	**5.1**
Sharks and rays – wildcatch	27,671	**5.5**
Scallops – wild catch	41,741	**6.3**
Prawns – wildcatch	117,749	**6.7**
Salmonids – farmed	561,128	**8.5**
Rock lobsters – wildcatch	89,851	**11.2**
Barramundi – farmed	46,265	**13.5**
Prawns – farmed	102,515	**15.2**
Tuna – farmed	149,459	**17.9**
	Total: 1,526,951	**Average:# 6.5**

* CO_2-e = Greenhouse gas emissions as carbon dioxide equivalent number.

Calculated as Total emissions (of sectors)/ total volume of production (of sectors). See Table 2 below.

Source: Blueshift Consulting

Of interest, the overall carbon estimation for the F&A sectors is more than double the NIBES reported emissions for the sectors. Further discussion on this is provided in the body of the report.

Other key findings are:

- Of the overall emissions in the two sectors, **Aquaculture** constitutes 900 kt CO_2-e or **59%** of the emissions, whilst produces 625 kt CO_2-e (**41%** of the total). Average **GHG intensity** for **Fishing** was estimated at nearly **4.4 kg CO_2-e** per kg of catch, whilst average intensity for **aquaculture** was estimated at **9.7 kg CO_2-e** per kg of product.
- Of the total emissions profile of both sectors, **purchased feed** (and bait) constituted the highest GHG emissions component of the entire profile, at just over 470 kt CO_2-e (31%), followed by (diesel) **fuel use** at just under 390 kt CO_2-e (25%) and **transport** of about 245 kt CO_2-e (16%).
- By production volume, the **largest industry GHG contributor** is the **salmonids industry** with 560 kt CO_2-e constituting 37% of total emissions whilst producing 28% of the volume and 34% by value of all domestic seafood production. The next most significant are the **Other Finfish** industry group with 280 kt CO_2-e (~18%) producing 22% of volume and 12% by value of domestic seafood production, **tuna farming** which produces 150 kt CO_2-e (nearly 10%), **prawn trawling** 118 kt CO_2-e (~8%), and **prawn farming** 102 kt CO_2-e (7%).
- In terms of emissions intensities, farmed tuna is the highest GHG intensity product, with nearly 18 kg CO_2-e per kg of product produced, thanks to a combination of the fuel used to catch the juvenile fish, GHG intensive feed inputs, and high transport costs to deliver products to distant export markets. The next most GHG intensive product is farmed prawns with 15.2 kg CO_2-e and farmed barramundi at 13.5 kg CO_2-e per kg of product produced. Rock lobster is the next most GHG intensive product at just over 11 kg CO_2-e per kg, and salmon at 8.5 kg CO_2-e per kg of fish produced.
- Significantly, the predominant emissions for the F&A sectors are **Scope 3**, totalling 52% of the total profile, of which 45% are derived from feed/bait, transport, and processing related costs, followed by Scope 1 emissions (fuel and fugitive emissions from refrigerant gases and N_2O) representing 31%.

A summary of the key findings is provided in Table 2 and Table 3 below (and in section 6). **Table 2** provides a summary and breakdown of emissions for the F&A sectors, and **Table 3** provides the data re-categorised as Scope 1, Scope 2, and Scope 3 emissions.

Project output - GHG emissions calculator tools

As part of the project work, three GHG emissions calculator tools were developed to help fishers and farmers better understand what drives their GHG emissions and how to measure them. And once they have been measured, what can be done to better manage emissions, and utilise the information in their operations and customer discussions. The tools are available for download from the Blueshift Consulting website: https://blueshiftconsulting.com.au/projects.

Project opportunities and recommendations

The project has identified five recommendations and opportunities for government departments and agencies to update and improve their GHG emissions reporting methodologies for the fishing and aquaculture sectors.

Keywords

Fishing, aquaculture, climate change, carbon, carbon emissions, greenhouse gases, carbon footprint

Table 2: Summary of GHG emissions Australian F&A sectors

Fishery/ species (Ranked by production volume)	Production method	Sector Fuel Usage (L)*	Fuel		Refrigerants		Purchased Power		Purchased Feed/ Bait		Processing		Transport		Aquatic N2O		Totals		% of total F&A	Notes
			kg CO2-e per kg	Sector (t CO2-e)	kg CO_2-e per kg	Sector (t CO2-e)	kg CO2-e per kg	Sector (t CO2-e)	kg CO2-e per kg	Sector (t CO2-e)	kg CO2-e per kg	Sector (t CO2-e)	kg CO2-e per kg	Sector (t CO2-e)	kg CO2-e per kg	Sector (t CO2-e)	kg CO2-e per kg	Sector (t CO2-e)		
Salmonids (Farmed)	Aquaculture - Cage culture		1	66,015	0.01	660	0.6	39,609	4.59	303,009	0.5	33,008	1	66,015	0.8	52,812	**8.5**	**561,128**	37%	1
Sardines	Fishing - Purse seine		0.5	21,139	0.01	423	0.3	12,683			0.5	21,139	0.3	12,683			**1.6**	**68,066**	4%	2
Other finfish	Fishing - Netting		2	124,560	0.2	12,456	0.8	49,824			0.5	31,140	1	62,280			**4.5**	**280,260**	18%	3
Prawns (wild catch)	Fishing - Trawl	27,076,852	4.2	73,649	0.2	3,528	0.8	14,112			0.5	8,820	1	17,640			**6.7**	**117,749**	8%	4
Rock Lobsters	Fishing - Pots	12,145,860	4.1	33,037			0.8	6,402	0.8	6,402	0.5	4,001	5	40,010			**11.2**	**89,851**	6%	5
Tuna (Farmed)	Cage culture		1	8,345	0.01	83	1.6	13,352	12	100,140	0.5	4,173	2	16,690	0.8	6,676	**17.9**	**149,459**	10%	6
Oysters (Farmed)	Aquaculture - Baskets	5,990,655	2.0	16,295	0.01	83	0.8	6,676			0.5	4,173	1	8,345	0.8	6,676	**5.1**	**42,248**	3%	7
Scallops	Fishing - Dredged		4	26,460	0.01	66	0.8	5,292			0.5	3,308	1	6,615			**6.3**	**41,741**	3%	8
Barramundi (Farmed)	Aquaculture - Pond/cage/ RAS		1	3,427	0.01	34	5.6	19,191	4.59	15,730	0.5	1,714	1	3,427	0.8	2,742	**13.5**	**46,265**	3%	9
Sharks/ Rays	Fishing - Netting / longline		2	10,062	0.2	1,006	0.8	4,025	1	5,031	0.5	2,516	1	5,031			**5.5**	**27,671**	2%	10
Prawns (Farmed)	Aquaculture - Pond/RAS		0.5	3,370	0.01	67	6.4	43,136	6	40,440	0.5	3,370	1	6,740	0.8	5,392	**15.2**	**102,515**	7%	11
Subtotals				**386,358**		**18,408**		**214,302**		**470,751**		**117,359**		**245,476**		**74,298**		**1,526,951**		

Notes:

* If data available via ATO data

1. **Salmonids (Farmed)** – Feed carbon intensity 4.59 kg CO_2-e per kg, based on Tassal Limited, 2021 Sustainability Report, page 38 'Total Carbon footprint of feed (CO_2-e/kg)'. Note that Tassal Ltd estimates total carbon footprint is 12kg CO_2-e/kg edible salmon meat) (page 14 of 2021 sustainability report).
2. **Sardines** – Note - Sardines are a special case, as the catch is predominantly utilised as feed for the tuna aquaculture industry in South Australia. The sardine fishery itself has a relatively low carbon footprint, it increases significantly when sardines are caught, processed, stored and then fed to farmed tuna.
3. **Other finfish** – Fuel analogue based on industry estimate for northern fisheries.
4. **Prawns (wild catch)** – High fuel use intensity. But is mitigated to some extent by no electricity and feed inputs, that create a relatively lower GHG emissions profile than for farmed prawns (source: Austral Fisheries, 2021).
5. **Rock lobsters** – Transport estimate based on long haul flight to northeast Asia.
6. **Tuna (farmed)** – Feed intensity based on *Macleod et al*. High use of sardines (see note above) creates a high GHG footprint related to feed. Power intensity based on Macleod and on existing prawn farm case studies.
7. **Oysters (farmed)** – n/a
8. **Scallops (dredged)** – Fuel intensity estimated, similar to prawn trawl.
9. **Barramundi (farmed)** – Feed carbon intensity based on salmon (source: Tassal Limited, 2021 Sustainability Report, page 38 (Best Case).
10. **Sharks/rays** – Fuel analogue based on industry estimate for northern fisheries (Austral).
11. **Prawns (Farmed)** – Feed intensity based on *Macleod et al*. Power intensity based on *Macleod et. al.* and on existing prawn farm case studies.

Table 3: Australian aquaculture & fisheries sector emissions (by scope) and segment (2019-20)

Sector Production					Scope 1					Scope 2				Scope 3				
	GVP $	Vol t	Emissions (tot)	CO_2-e/kg	Fuel	Refri-gerant	N_2O	Subtotal	% of tot	Power	Process	Subtotal	% of tot	Feed/bait	Transport	Process	Subtotal	% of tot
Fishing	**1,201**	**143,554**	**625,337**	**4.4**	288,906	17,479		306,385	49%	92,338		92,338	15%	11,433	144,259	71,094	226,786	36%
%	**46%**	**61%**	**41%**															
Sardines	$30	42,277	68,066	1.6	21,139	423	0	21,561	32%	12,683	0	12,683	19%	0	12,683	21,139	33,822	50%
Other Finfish	$372	62,280	280,260	4.5	124,560	12,456	0	137,016	49%	49,824	0	49,824	18%	0	62,280	31,140	93,420	33%
Prawns WC	$233	17,640	117,749	6.7	73,649	3,528	0	77,177	66%	14,112	0	14,112	12%	0	17,640	8,820	26,460	22%
Rock Lobsters	$521	8,002	89,851	11.2	33,037	0	0	33,037	37%	6,402	0	6,402	7%	6,402	40,010	4,173	50,584	56%
Scallops	$18	6,615	41,741	6.3	26,460	66	0	26,526	64%	5,292	0	5,292	13%	0	6,615	3,308	9,923	24%
Shark rays	$27	6,740	27,671	4.1	10,062	1,006	0	11,068	40%	4,025	0	4,025	15%	5,031	5,031	2,516	12,578	45%
Aquaculture	**1,390**	**92,872**	**901,614**	**9.7**	97,452	929	74,298	172,678	19%	121,964	46,436	168,400	19%	465,720	101,217	0	566,937	63%
%	**54%**	**39%**	**59%**															
Salmonids	$890	66,015	561,128	8.5	66,015	660	52,812	119,487	21%	39,609	33,008	72,617	13%	303,009	66,015	0	369,024	66%
Tuna	$137	8,345	149,459	17.9	8,345	83	6,676	15,104	10%	13,352	4,173	17,525	12%	100,140	16,690	0	116,830	78%
Oysters	$137	8,345	42,248	5.1	16,295	83	6,676	23,054	55%	6,676	4,173	10,849	26%	6,402	8,345	0	14,747	35%
Barra	$91	3,427	46,265	13.5	3,427	34	2,742	6,203	13%	19,191	1,714	20,905	45%	15,730	3,427	0	19,157	41%
Prawns	$135	6,740	102,515	15.2	3,370	67	5,392	8,829	9%	43,136	3,370	46,506	45%	40,440	6,740	0	47,180	46%
TOTALS	**2,591**	**236,426**	**1,526,951**	**6.5**	386,358	18,408	74,298	479,063	31%	214,302	46,436	260,738	17%	477,153	245,476	71,094	793,723	52%

* fisheries information source: *Steven, AH, Dylewski, M and Curtotti, R 2021, Australian fisheries and aquaculture statistics 2020, Fisheries Research and Development Corporation, ABARES, Canberra, August.*

1. Introduction

Our early carbon insights screamed opportunity… If we were able to offer a consumer who shared our values, a carbon neutral product, then we might just find that our leadership would be rewarded with loyalty and a premium… (David Carter, CEO Austral Fisheries, TEDx talk, 2021).

a) Aims & objectives

This project, *Energy use and carbon emissions assessments in the Australian fishing & aquaculture sectors*, represents the first attempt to gain an overall picture of the carbon footprint of the Australian seafood production sectors, derived from the wild-catch fishing and aquaculture (F&A) industries.

Specifically, the project had three principal programs and objectives:

Program 1: Establish energy use and greenhouse gas (GHG) emissions profile of Australian Fishing and Aquaculture sectors

Program 2: Develop a self-assessment tool for the Australian Fishing and Aquaculture sectors - to calculate energy efficiency and GHG emissions, and

Program 3: Develop a toolbox and examples for emissions reduction opportunities in the Fishing and Aquaculture sectors.

Each program, including its aims, methods, results, and discussion are detailed in the following chapters.

Prior to discussing each of the programs and their results, some background on the following aspects is provided:

- discussions on the drivers and need for GHG reporting and information uses in the seafood industries, and
- discussion on current Australian energy and GHG reporting frameworks.

For additional context, a detailed background on greenhouse gases, the greenhouse effect and international and national regulatory frameworks underpinning reporting of emissions is also provided.

b) Prior FRDC research

The Fisheries Research and Development Corporation (FRDC) has led research and development (R&D) into the Australian seafood sector for over 50 years. Historically, FRDC's work has focussed on fish ecology, fisheries health, harvest efficiencies, catch monitoring, and over the last two decades moving more into fisheries economics, sustainable fisheries, environmental, social, and financial assessment of Australian fisheries to the broader economy. In the last decade, FRDC has been clearly focussed on 'sustainable seafood' and has dramatically expanded its support of aquaculture as this sector has grown to be the predominant seafood producer. And whilst FRDC has sponsored several research projects into opportunities and challenges for the Australian F&A sectors in the carbon economy, to date there has not been a comprehensive audit of energy use, GHG emissions of the Australian F&A sectors, or carbon footprints of seafood products.

This is not a criticism of FRDC, but merely a reflection on the ongoing politico-scientific debate around carbon emissions and climate change which has ebbed and flowed for the last 30 years, and which only in the last 18 months has gained unprecedented momentum and impetus for R&D and action plans. Globally, whilst there has been a recent flurry of activity in GHG emissions quantification, reporting and reduction in many parts of the agri-food sectors, as well as consumer-driven reporting and tools regarding carbon footprints of food products, globally the seafood sectors have come relatively late to these initiatives.

Contributing to this, within the Australian GHG emissions reporting frameworks, the F&A sectors have been included within the 'Agriculture' aggregated segment. The agriculture sector's overall GHG footprint is significant, but the F&A components' – which are relatively small gross value of production (GVP) within the overall aggregation – have received limited attention by the GHG statisticians and national emissions reports.

Nonetheless, wild-caught and aquaculture seafood production has for the last decade faced increasing pressures and scrutiny regarding its overall sustainability. Wild-catch harvests have been reported by government for decades but now are also closely analysed by well-funded non-governmental organisations (NGOs)[1]. Australia's aquaculture production volume, which has just recently exceeded that of wild-caught seafood, is also closely monitored nationally and internationally.[2] In Australia, farmed salmonids, now our largest fishery[3], and part of the huge global salmon production sector, is facing greater regulatory, NGO, shareholder, and consumer scrutiny over sustainability issues.

In the fishing and aquaculture sectors, the carbon footprint of seafood products will become increasingly important to support sustainability claims and the ongoing viability of the industry.

i. Australian & international contemporary research

Summaries of relevant previous FRDC research and contemporary Australian and international research into energy efficiency, carbon emissions, carbon measurement, and 'footprinting' in the seafood sectors is provided in Appendix 1.

c) Need for more information on GHG emissions

In addition to the increased stakeholder scrutiny on fisheries and aquaculture, there are several other important drivers and needs for further information on energy use and greenhouse gas (GHG) emissions in the Australian fisheries and aquaculture sectors. These include:

- **Disaggregated, accurate data for the F&A sectors**. GHG data collected for the F&A sectors is aggregated and reported within the Agriculture, Forestry & Fishing Industry (AFF Industry) classification within Australia's National Inventory. The AFF Industry sector is broad and is the second largest GHG emitter in the Australian accounts and therefore receives much attention from government, NGOs, and the public regarding emissions reduction. There are good commercial reasons and indeed an imperative for the F&A sectors to provide a clear, disaggregated, determined, and differentiated assessment of its contributions within this large, aggregated sector.
- **Establishment of F&A sectors GHG baselines**. The output from the above is to seek to develop industry baselines against which further performance can be measured (and potentially benchmarked against other food production sectors).
- **Ability for sectors, subsector/industries, and companies to measure and manage their energy use and GHG emissions**. There is a need for subsectors (specific managed fisheries or industry groups) as well as individual companies to be able measure, assess and then potentially manage their own energy use, as energy costs continue to increase and as the imposition of financial penalties for GHG emissions – from government, shareholders, and consumers – becomes more likely.
- **Greater and better data provides opportunities**. Finally, once the F&A sectors, subsectors and companies have data, further education, and tools to assist them to improve energy efficiency and profitability, lower emissions and related risks are needed. In addition, it will be increasingly

[1] See Minderoo Foundation, Global Fisheries Index, published 20 November, 2021 at: https://www.minderoo.org/global-fishing-index/ , accessed 22/11/21.
[2] See the Coller FAIRR Protein Producer Index (release published 1 December, 2021) at: https://www.fairr.org/index/ .
[3] The term 'fishery' has been used more broadly to signify any 'fish production' enterprise to cover wild-caught and farmed fish.

important for the seafood industry to create positive engagement with stakeholders around GHG emissions and decarbonisation – particularly to customers which are becoming more discerning in product selection based on carbon footprints – to maintain competitiveness in consumer protein decision-making and food selection.

d) Australia's energy use & GHG measurement programs

A background on greenhouse gases (GHGs), energy use and GHG emission reporting frameworks and requirements and the status of national reporting is provided below.

i. Australia's greenhouse gas international reporting framework

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

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

In undertaking these commitments, the Australian government has established several GHG measurement, accounting, and reporting processes. Each is outlined below.

In addition, following the COP26 in November 2021 and the Glasgow Climate Pact, Australia has updated and enhanced our Nationally Determined Contribution (NDC) under the Paris Agreement to include:

- net zero emissions by 2050 target
- updated emissions projections that aim for Australia to achieve up to a 35% reduction by 2030, and
- new targets in the form of low emissions technology stretch goals.

In addition, the Australian government has committed to operation of international carbon markets, increased reporting and accounting transparency, an Indo-Pacific Carbon Offsets Scheme, a $2 billion climate finance commitment over the next five years, and the Glasgow Breakthroughs Initiative, which sets global goals to make clean technologies an affordable and accessible option before 2030.

ii. What are GHGs & GWPs?

Greenhouse gases (GHGs) are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself and by clouds. This property causes the greenhouse effect.

Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) are the primary GHGs in the Earth's atmosphere. Carbon dioxide enters the atmosphere through burning fossil fuels (coal, natural gas, and oil), solid waste, trees and other biological materials, and as a result of certain chemical reactions (e.g. manufacture of cement). Carbon dioxide is removed from the atmosphere (or "sequestered") when it is absorbed by plants as part of the biological carbon cycle. Methane is emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from livestock and other agricultural practices, land use and by the decay of organic waste in municipal solid waste landfills. Nitrous oxide is emitted during agricultural activities, land use, industrial activities, combustion of fossil fuels and solid waste, as well as during treatment of wastewater.

Moreover, there are several entirely human-made GHGs in the atmosphere, such as the halocarbons and chlorine- and bromine-containing substances, such as sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) which have high global warming potentials (GWP), compared to CO_2.

GHGs differ from each other in two main ways: their ability to absorb energy (their ‘radiative efficiency’); and how long they stay in the atmosphere (also known as their ‘lifetime’). The Global Warming Potential (GWP) measures were developed to allow comparisons of the global warming impacts of different gases. Specifically, it is a measure of how much energy the emissions of 1 tonne of a gas will absorb over a given period, relative to the emissions of 1 tonne of carbon dioxide (CO_2). The larger the GWP, the more that a given gas warms the Earth compared to CO_2 over that period. The period usually used for GWPs is 100 years. GWPs provide a common unit of measure, which allows analysts to add up emissions estimates of different gases (e.g. to compile a national GHG inventory) and allows policymakers to compare emissions reduction opportunities across sectors and gases.

What are ‘greenhouse’ gases?

Greenhouse gases or GHGs, 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 or CO2) is the primary greenhouse gas emitted through human activities. In 2019, CO_2 accounted for about 80% of all greenhouse gas emissions from human activities.

Carbon dioxide is naturally present in the atmosphere as part of the Earth's carbon cycle (the natural circulation of carbon among the atmosphere, oceans, soil, plants, and animals). Human activities are altering the carbon cycle – both by adding more CO_2 to the atmosphere, and by influencing the ability of natural sinks, like forests and soils, to remove and store CO_2 from the atmosphere. While CO_2 emissions come from a variety of natural sources, human-related emissions are responsible for the increase that has occurred in the atmosphere since the industrial revolution.

Enormous amounts of CO_2 are continually exchanged between the atmosphere, land, and oceans, as land and marine plants grow, die and decay, and as carbon-rich waters circulate in the ocean. For several thousand years until around 200 years ago, this ‘carbon cycle’ was approximately in balance and steady. Since the 19th century, human-induced CO_2 emissions from fossil fuel combustion, cement manufacture and deforestation have disturbed the balance, adding CO_2 to the atmosphere faster than it can be taken up by the land biosphere and the oceans. On average over the last 50 years, about 25% of total CO_2 emissions were absorbed by the ocean making sea water more acidic and 30% was taken up on land, largely by increased plant growth stimulated by rising atmospheric CO_2, increased nutrient availability, and responses to warming and rainfall changes (though the mix of these mechanisms remains unclear). The other 45% of emissions accumulated in the atmosphere. These changes to the carbon cycle are known from measurements in the atmosphere, on land and in the ocean, and from modelling studies.

The six ‘priority’ greenhouse gases (GHGs) as listed in the Kyoto Protocol[4] for accounting of GHG profiles are:

- carbon dioxide (CO_2)
- methane (CH_4)
- nitrous oxide (N_2O)
- hydrofluorocarbons (HFCs)
- perfluorocarbons (PFCs)
- sulphur hexafluoride (SF6)

Greenhouse gas emissions are measured as tonnes of carbon dioxide equivalence (CO_2-e) using the Global Warming Potential (GWP) weighting factors indicated in Table 4 below. GWPs have been used for each of the major greenhouse gases to convert them to carbon dioxide equivalents (CO_2-e).

This means that the amount of a greenhouse gas emitted is measured as an equivalent amount of carbon dioxide, which has a global warming potential of one. For example, one tonne of methane released into the atmosphere will cause the same amount of global warming as 28 tonnes of carbon dioxide. So, the one tonne of methane is expressed as 28 tonnes of carbon dioxide equivalence, or **28 t CO_2-e.**

[4] The Kyoto Protocol (see: https://unfccc.int/kyoto_protocol) is a United Nations initiative and international commitment ratified by 192 nations operationalising the United Nations Framework Convention on Climate Change (UNFCCC) by requiring industrialized countries and economies in transition to limit and reduce greenhouse gases (GHG) emissions in accordance with agreed individual targets. The Convention seeks to commit those countries to adopt policies and measures on mitigation and to report GHG emissions periodically.

Also, as greenhouse gases vary in their radiative activity and in their atmospheric residence time, converting emissions into CO_2-e allows the integrated effect of emissions of the various gases to be compared.

a) *Paris Agreement update to GWPs for emission estimation*

Commencing with the September Quarter 2020 the Australian Government's Department of Industry, Science, Energy & Resources (DISER) has applied the 100-year time GWP values from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) to estimate emissions, consistent with rules adopted under the UN Framework Convention on Climate Change (UNFCCC) Paris Agreement (Decision 18/CMA.1 Annex 2.D Paragraph 37).

This approach formed the basis to track Australia's progress towards its Paris Agreement Nationally Determined Contribution (NDC) of 26-28% below 2005 levels by 2030, on an emissions budget basis.

Prior to the DISER September 2020 Quarterly report, the GWPs used were the 100-year time-horizon GWPs contained in the 2007 IPCC Fourth Assessment Report of Climate Science (AR4), in accordance with previous UNFCCC decisions.

Table 4 compares the IPCC Fifth and Fourth Assessment Reports' 100-year GWPs.

Table 4: Comparison of the IPCC Fifth and Fourth Assessment Reports' 100-year GWPs

Major greenhouse gases	2007 4th Assessment Report GWP (Table 2.14)	2020 5th Assessment Report GWP (Table 8.A.1)
Carbon dioxide (CO_2)	1	1
Methane (CH_4)	25	28
Nitrous oxide (N_2O)	298	265
Perfluorocarbon - CF4	7,390	6,630
Perfluorocarbon – C2F6	12,200	11,100
HFC-23	14,800	12,400
HFC-32	675	677
HFC-41	92	116
HFC-43-10mee	1,640	1,650
HFC-125	3,500	3,170
HFC-134	1,100	1,120
HFC-134a	1,430	1,300
HFC-143	353	328
HFC-143a	4,470	4,800
HFC-152	53	16
HFC-152a	124	138
HFC-161	12	4
HFC-227ea	3,220	3,350
HFC-236cb	1,340	1,210
HFC-236ea	1,370	1,330
HFC-236fa	9,810	8,060
HFC-245ca	693	716
HFC-245fa	1,030	858
HFC-365mfc	794	804
Sulphur hexafluoride (SF_6)	22,800	23,500

Australia's emissions of the greenhouse gas nitrogen trifluoride (NF_3) are considered negligible and are not estimated.

iii. GHG emission 'scopes'

GHG emissions are reported in three categories or 'scopes' depending on how they are generated or derived, as follows:

- **Scope 1 – Direct Emissions**. GHG emissions from *combustion of fuels* such as diesel, petrol, and gas
- **Scope 2 – Indirect Emissions**. GHG emissions derived from the *generation of electricity*, *consumed* by an enterprise

- **Scope 3 – Indirect Emissions (other than scope 2)**. GHG emissions *generated in the wider economy because of the activities of an enterprise/facility*, but from *sources not owned or controlled by that enterprise/facility*. Some Scope 3 examples are emissions:
    - from sourcing and production of purchased input materials
    - from or associated with transportation of purchased inputs, fuels, services, and sold products, and
    - associated with the use of sold products.

Scope 1 and Scope 2 emissions are relatively easy to determine and calculate. However, determining Scope 3 emissions can be difficult, and often requires detailed assessment of all the inputs to a manufacturing/production process and tools such as life cycle analysis (LCA) to determine.

Emissions are typically reported in tonnes (sometimes abbreviated as Mt for 'metric tons' in the USA which does not use the metric/SI units system, not to be confused with 'megatonnes' – see below). In addition, large emissions are reported in multiples such as kilo (metric) tonnes (kT), and megatonnes (Mt). Direct emissions of some gases are also sometimes reported in gigagrams (10^9 grams) where 1 gigagram (1gG) equals 1 megatonne (1Mt).

iv. COP26 Glasgow

As indicated above, as an outcome of the 22nd Conference of the Parties (COP22) to the UNFCCC Agreement meeting in Paris in 2015, 175 nations signed the Paris climate agreement as parties. Signatories agreed to work to limit global temperature rise this century to less than 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5°C.

By the end of COP26, six years after Paris, 151 countries had submitted new climate plans (known as nationally determined contributions, or NDCs) to meet the goal of limiting temperature rise to 1.5°C and to slash their emissions in half by 2030. However, the United Nations calculates that these plans, as they stand, still put the world on track for 2.5°C of warming by the end of the century, but which is better than the 4°C trajectory the world was on before the Paris Agreement was struck.

Considering countries' commitments to reach net-zero emissions by around 2050, analysis shows temperature rise could be kept to around 1.8 or 1.9°C. But some major emitters' 2030 targets are comparatively weak and don't offer credible pathways to achieve net-zero targets. However, the Glasgow decision calls on countries to "revisit and strengthen" their 2030 targets by the end of 2022 to align them with the Paris Agreement's temperature goals. It also asks all countries that have not yet done so, to submit long-term strategies to 2050, aiming for a just transition to net-zero emissions around mid-century. Together, stronger NDCs and long-term strategies should help align the net-zero and 2030 targets, as well as ramping up ambition. Elsewhere, the COP26 decision says that countries "resolve to pursue efforts to limit the temperature increase to 1.5°C" which gives this lower temperature threshold even greater emphasis than in the Paris Agreement.

In addition, the pact asks nations to consider further actions to curb potent non-CO_2 gases, such as methane, and includes language emphasizing the need to "phase down unabated coal" and "phase-out fossil fuel subsidies." This marked the first occasion that negotiators have explicitly referenced shifting away from coal and phasing out fossil fuel subsidies in COP decision text.

And lastly, this latest COP finally recognized the importance of nature for both reducing emissions and building resilience to the impacts of climate change, both in the formal text and through a raft of initiatives announced on the sidelines.

v. Australian National Greenhouse Accounts

The Australian government Department of Industry, Science, Energy & Resources (DISER) publishes a series of reports and databases that estimate, and account for, Australia's greenhouse gas emission estimates from 1990 onwards. Together these products comprise the National Greenhouse Accounts (National Accounts).

Australia's National Greenhouse Accounts are comprised of the:

- National Inventory Report prepared under the reporting provisions applicable to the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol (KP)
- Quarterly Update of Australia's National Greenhouse Gas Inventory
- State and Territory Greenhouse Gas Inventories
- National Inventory by Economic Sector.

The objectives of the National Accounts are to:

- fulfil Australia's international greenhouse gas inventory reporting commitments
- provide the official basis for tracking progress towards, and assessing compliance with, Australia's emission reduction commitments
- support the design, implementation, and evaluation of domestic emission reduction policies, and
- inform future emission reduction commitments.

The emission estimates for these inventories are prepared in accordance with international guidelines and are subject to annual review by international experts. The methodologies for the estimation of emissions are in Australia's National Inventory Report.

vi. Australia's National Inventory Reports

Australia fulfils its international greenhouse gas inventory reporting commitments by submitting annual National Inventory Reports to the United Nations Framework Convention on Climate Change (UNFCCC).

Emission estimates are compiled consistent with:

- UNFCCC Reporting Guidelines on Annual Inventories and the supplementary reporting requirements under the Kyoto Protocol
- the Intergovernmental Panel on Climate Change (IPCC) 2006 Guidelines for National Greenhouse Gas Inventories (the Guidelines)
- the IPCC 2019 Refinement of the 2006 IPCC Guidelines
- the IPCC 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol, and
- country-specific methodologies consistent with the Guidelines and intended to improve emissions accuracy.

Australia mostly uses country-specific methodologies and emissions factors in compiling its National Inventory Reports. The methodologies used to estimate Australia's inventory have been improved over time and continue to be refined as new information emerges, and as international practice evolves.

Australia's last National Inventory Report 2019 (at the time of this project publication) was submitted to the UNFCCC in April 2021.

vii. National Greenhouse Gas Inventory: Quarterly Updates

Quarterly Updates of Australia's National Greenhouse Gas Inventory are the most up to date source of information on Australia's national emissions. They provide a summary of Australia's national emissions, updated on a quarterly basis. They are aimed to provide up-to-date information to policy makers, markets, and the public to demonstrate how Australia is tracking against its targets.

Relevant to this report, the National Greenhouse Gas Inventory: Quarterly Update issued in September 2021 is referenced in this report.

viii. State and Territory Greenhouse Gas Inventories

Each of the States and Territories also compile Greenhouse Gas Inventories of their respective emissions. These inventories are a disaggregation of the data contained in the National Inventory Report submitted to the UNFCCC each year.

The last State and Territory Greenhouse Gas Inventories produced were for the 2019 reporting period.

ix. National Inventory by Economic Sector

The National Inventory by Economic Sector (NIBES), provides greenhouse gas emission estimates by economic sector utilising the Australia-New Zealand Standard Industry Classifications (ANZSIC) rather than by International Panel on Climate Change sector. These inventories are a disaggregation of the data contained in the National Inventory Report submitted to the UNFCCC each year.

The economic sectors are:

- Primary industries: agriculture, forestry and fishing; mining
- Manufacturing
- Electricity, gas, water and waste services
- Services, construction and transport
- Residential.

Under the sector 'Primary industries', the subsector 'fishing' also includes aquaculture.

The latest published accounts used in this report are the National Inventory by Economic Sector 2019 which forms part of an interactive issue of the National Accounts.

x. Australian Greenhouse Emissions Information System

The Australian Greenhouse Emissions Information System (AGEIS) is an online database that provides detailed greenhouse gas emissions data from the National Greenhouse Accounts—except for Quarterly updates. Data can be queried through a dynamic interface and search function.

xi. National Greenhouse Accounts Factors

The National Greenhouse Accounts Factors (NGA Factors) provides methods to help companies and individuals estimate greenhouse gas emissions. The NGA Factors are provided for the purpose of emissions estimation outside of the NGER Act. The NGERS Measurement Determination and associated NGER regulations are the legislative instruments published for the purposes of reporting under the NGER Act.

xii. National Greenhouse and Energy Reporting Scheme

The National Greenhouse and Energy Reporting (NGER) scheme is a single national framework for reporting company greenhouse gas and energy production and consumption data. The reported greenhouse gas emissions data in the NGER scheme are an important input into the preparation of the National Greenhouse Accounts.

Tassal Group Ltd is the only F&A sector company which exceeds the reporting threshold, and reports its energy consumption and greenhouse gas (GHG) emissions to the Commonwealth Government annually under the National Greenhouse and Energy Reporting (NGERS) scheme.

e) Alignment with FRDC R&D Strategic Plan 2025

The FRDC's Vision to 2030, strategic context, enabling strategies and R&D plan outcomes are detailed in its R&D Strategic Plan 2020 – 2025 (the R&D Plan). The R&D Plan specifies that FRDC investment will be targeted to achieve five key **outcomes** being:

1. Growth for enduring prosperity
2. Best practices and production systems
3. A culture that is inclusive and forward thinking
4. Fair and secure access to aquatic resources
5. Community trust, respect and value.

The plan focuses on capacity building, shaping culture, building relationships, and establishing shared principles and values. To help make progress towards these outcomes easier, the FRDC will use five **enabling strategies** to realise the highest potential from investments made for fishing and aquaculture, specifically:

I. Drive digitisation and advanced analytics
II. Strengthen adoption for transformative change
III. Promote innovation and entrepreneurship
IV. Build capability and capacity
V. Provide foundational information and support services.

The five outcomes in FRDC's R&D Plan align with 14 of the 17 United Nations Sustainable Development Goals (SDGs), with Climate Change being SDG 13. On a strategic front, the FRDC has acknowledged that '*Climate variability and longer-term change is occurring across the world and will bring a myriad of ecological and biological variation that need altered policies specific to fishing and aquaculture*'.[5]

This project aligns with several of the FRDC R&D Plan outcomes and enabling strategies. The 'emissions profiling' component aligns clearly within *Enabling Strategy V: Provide foundational information and support services*, as the FRDC foresees a future with 'more holistic reporting of performance'.

THE FUTURE: More holistic reporting of performance

Looking forward, performance will be measured by more than target stock sustainability and GVP. More producers will need to tell a story—supported by evidence—about their bycatch levels, carbon footprint, wellbeing of fishers and farmers, quality along the value chain, and how benefits will be distributed. Transforming performance reporting for fisheries and aquaculture will involve being able to collect new information both cheaply and effectively, although this may take years to be fully implemented.

The 'energy efficiency' component of the project, clearly aligns with *Outcome 2: Best Practices and production systems*, which acknowledges that 'ethical' businesses will have… 'benefits including improved reputation, reduced risk, competitive advantage, access to new markets and value creation'… and that these 'industries and sectors are responding by adopting practices that have less impact on the environment or are even regenerative' and… 'also consider the wellbeing of workers, communities and consumers, conserve non-renewable energy, sustainably manage natural resources, minimise stress in animals, and do not compromise the needs of future generations'.

[5] FRDC 2020, *Imagining the future of fishing and aquaculture*, FRDC's R&D Plan 2020–25, Canberra, June 2020. CC BY 3.0

The project also aligns with *Enabling Strategy I: Drive digitisation and advanced analytics*, which acknowledges the impact of technology on the F&A sectors and how 'new technologies' present opportunities for fishing and aquaculture to easily combine and analyse data to make decisions that reduce costs and increase benefits. Commercial wild-catch fishers will have access to data previously unavailable, including near real-time information on:

- gear performance and efficiency
- costs and usage of energy and other inputs
- behaviour and distribution of target species
- markets and prices.

In the 2019-20 planning workshops for the development of FRDC's R&D Plan 2020–25, in the scenario planning exercise, several envisaged futures with 'consumer phone-based apps to tell tales of provenance, harvest methods, and carbon footprints', a 'carbon-positive fishing and aquaculture community', carbon tax and full-cost accounting measures implementation and where 'sectors of the F&A community are minimising carbon footprint and being transparent about it…'.

2. Energy use and greenhouse gas profiles of Australian Fishing and Aquaculture sectors (Program 1)

a) Background

The overall objective of Program 1 was to undertake a high-level assessment of energy use and GHG emissions in the Australian fishing and aquaculture (F&A) sectors. Whilst there has been some background research (some undertaken by FRDC) primarily in energy efficiency, this project is the first attempt to characterise the energy use and GHG profile of Australia's domestic seafood production industry.

b) Methodology

For this project, the F&A sectors are characterised as:

- Fishing sector – all wild-catch fishing industries, methods, and species, including inland and marine
- Aquaculture sector– all aquaculture including inland and marine and
  - Land-based (ponds, tanks)
  - Ocean-based (cages).

Where appropriate the two are categorised together as the F&A sectors, or separately as the Fishing sector and the Aquaculture sector. Further, each sector is often subdivided into subsectors, industries, or species e.g. prawns, which may include both wild catch and aquaculture production.

i. Initial approach

The Australian National Greenhouse Accounts (National Accounts) contains carbon emissions of the Australian F&A sectors reported within the overall 'industry' aggregation of 'Agriculture, Forestry & Fishing' (**AFF aggregation**). This project commenced with the expectation that comprehensive GHG emissions data would be available at sectoral and industry levels for the Australian F&A sectors within the National Accounts, which we would then access and interrogate and analyse, to obtain high-level, 'top down' estimates of the F&A sector emissions (for last reporting year, 2019).

However, further investigations and discussions with the Department of Industry, Science, Energy and Resources (DISER), responsible for assembling the National Accounts, revealed:

- data for the F&A sectors, reported within the AFF aggregation are not gathered from industry reported metrics, but are estimates only, calculated as a percentage of the overall Agriculture emissions (this is discussed further below)
- aquaculture and fisheries are separated further into two numbers, but:
  - the **aquaculture** GHG emissions number reported is calculated as a percentage of the fisheries estimate, but relatively does accurately reflect the scale of aquaculture operations in Australia, and
  - there is no further detail or disaggregated figures for within the two sectors, and
- F&A is not a major focus area for energy management or GHG data collection by the DISER (viz. the sectors are relatively small within the overall AFF aggregation).

Nonetheless, this outcome was contemplated during the project proposal stage and based on these findings, some alternative methods for gathering information regarding energy use/GHG emissions were undertaken, as detailed in **section ii** below.

ii. Revised methodology

As indicated above, our initial findings were that a 'top-down' approach of disaggregating and interrogating the large National Accounts data sets was unable to provide meaningful data for the Australian F&A sectors GHG emissions.

However, several alternate methods were employed which included:

- analysis of the Australian Tax Office (ATO) *Fuel Tax Credit Scheme* data[6] (particularly relevant for fisheries and cage-culture aquaculture)
- collection of reported and anecdotal industry and company data for fuel use and electricity emissions (and Scope 3 emissions); and
- analysis of Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) fisheries and aquaculture data which could be incorporated with the industry/corporate information, to attempt to undertake 'bottom-up' extrapolations of total fishery/subsector estimations of GHG emissions, and
- consultations with some of the larger and leading companies in the aquaculture and fishing sectors.

This approach was aimed at determining an F&A account of energy use and GHG emissions with disaggregated sectoral data, provided in as much detail as possible from existing data, but without attempting at this stage to seek more detailed information directly from those sectors. This in turn, was based on industry feedback that voluntary reporting surveys may not be effective in gathering adequate and reliable data and attempts to seek more explicit information on a voluntary basis, could have a low level of response.

This also somewhat drove the scope for the other two objectives for the project, namely:

- to focus efforts on enabling F&A operators to undertake **self-assessment** and determine their energy use and emissions (outlined in **Program 2**); and
- after self-assessment – to provide **guidance** to F&A operators on **how to manage and best use this information** to make their businesses more efficient, but also how to best utilise it in interactions with customers, the public and stakeholders for commercial advantage (outlined in **Program 3**).

c) Key findings

Key findings from Program 1 are detailed in this section, within the following headings:

i. Characterisation of F&A activities and methods creating GHG emissions
ii. Reported GHG emissions of the Australian F&A sectors
iii. Current methods for energy use and GHG data capture and reporting for the F&A sectors in Australia
iv. Data issues with current Australian government GHG data capture and reporting for the F&A sectors

[6] Fuel tax credits provide businesses with a credit for the fuel tax (excise or customs duty) that is included in the price of fuel used in: Machinery; plant; equipment; heavy vehicles; light vehicles travelling off public roads or on private roads. Some fuels and activities are not eligible including fuel you use in light vehicles of 4.5 tonnes gross vehicle mass (GVM) or less, travelling on public roads.

v. Recommendations for improvements of data collection, estimation, and reporting of GHG emissions, and

vi. Other potential and useful indicators/measures of GHG emissions in the F&A sectors.

i. Characterisation of fishing and aquaculture activities creating GHG emissions

The Australian F&A sectors are made up of a wide array of fisheries and variety of catching and production methods. Before seeking to determine industry/subsector emissions, it is useful to review these methods, and how they utilise and incorporate energy into their catching and production operations and their implications for emissions.

a) Overview of Fishing & Aquaculture

Australia's domestic seafood production industry is comprised of wild-catch fishing and aquaculture. For the purposes of this project, wild-catch fisheries and aquaculture have been separated into two sectors – F&A. However, in some of the State and National reporting, the two are collectively referred to as simply 'fisheries'.

Wild-catch fishing takes place in rivers, estuaries, coastal and oceanic seas, predominantly using boats and ships, and target a multitude of species with catch landings occurring mostly in regional areas. Aquaculture is undertaken in two basic operating methods. The first is on land, where mainly fish, prawns and other crustaceans are grown, predominantly in northern Australia in ponds, or in tanks in other parts of Australia. The second, and largest by volume and value, is undertaken in sea cages, sited in coastal waters of Tasmania and South Australia, focused on a small range of species, predominated by Atlantic salmon, but also tuna, and kingfish. In both these aquaculture methods the animals are fed. In addition, oysters are grown in intertidal and shallow tidal areas along the coastlines and estuaries of most states and the NT. Increasingly, mussels and seaweed aquaculture is being undertaken in subtidal, oceanic, and land-based systems, which along with oysters – a large aquaculture industry – constitutes 'non-fed' aquaculture.

Historically, the wild-catch sector has accounted for most of the gross value of production (GVP) of Australia's seafood production industry. However, in line with the global rise in aquaculture production in the past two decades, Australia's aquaculture sector has been steadily increasing its real value (GVP) and proportional share of the overall domestic seafood production volume and GVP. This trend has been driven largely by increased production of farmed salmonids and a declining trend in wild-caught production. In addition, the aquaculture sector has been broadening the composition of species produced – with increased emphasis on prawns, abalone, oysters, and other finfish varieties, including barramundi and kingfish.

Recent data indicate that real GVP of the aquaculture sector and the wild-caught sector were approximately equal in 2019–20. However, in 2021–22, aquaculture GVP exceeded wild-caught GVP for the first time. However, during this reporting period, both sectors were challenged by the impacts of COVID-19 which had varied effects on demand and price for high-value export commodities, increased domestic sales but often lower prices.

Key features of the Australian F&A sectors are:

- Total (2018) primary production of domestic seafood was nearly 266,570 tonnes worth about $3.2 billion (GVP). In 2020, primary production of domestic seafood increased by 4.4% to 280,830 tonnes but worth about $3.15 billion (GVP), down nearly 2%.
- The Australian commercial fisheries and aquaculture industry produces a diverse range of products, but the majority of the GVP is comprised by a relatively small number of species. This concentration in production means that just three species groups (salmonids, rock lobster and prawns) account for around 60% of the GVP of Australian fisheries and aquaculture, and almost the entire production can be characterised into 9 major groups.

Table 5 below provides an overview of Australia's largest fisheries by GVP, their catch/production methods.

Table 5: The largest fisheries by value within the Australian F&A sectors, with catch & production methods

Rank (GVP)	Species/Fishery	Catch/ production technique	Production 2019					
			(GVP m$)			(tonnes)		
			Wild	Aqua	Total	Wild	Aqua	Total
1	Salmonids	Coastal cage culture	-	$890	$890		66,015	66,015
2	Rock lobster	Traps/pots	$521	-	$521		8,002	8,002
3	Other finfish	Trawl, nets, line	$372	-	$372	62,280		62,280
4	Prawns	Trawl & pond culture	$233	$134	$367	17,640	6,740	24,380
5	Other crustaceans & molluscs	Traps, pond, coastal lines	$81	$6	$87	6,731	2,342	9,073
6	Abalone	Hand caught, tank culture	$118	$22	$140	2,309	549	2,858
7	Tuna	Cage culture/ranching, line	$73	$137	$210	8,708	8,345	17,053
8	Edible oysters	Coastal culture	-	$114	$114	-	9,011	9,011
9	Other NEI (e.g. barramundi)	Pond culture, cage culture	-	$164	$164	-	8,776	8,776

- Salmonids are almost totally produced by coastal cage aquaculture. Rock Lobster is a wild-catch fishery utilising large numbers of pots/traps. Prawns are predominately from wild-catch trawl fisheries with about a quarter derived from aquaculture. Other tropical and temperate finfish species (including barramundi, snappers, whiting, mullet, mackerel, ling are predominantly wild-caught, whilst other crustaceans and molluscs (scallops, crabs, mussels, squid) are predominantly derived from aquaculture with about 40% wild-caught.
- Abalone is about 80% wild-caught by diving operations, with about 20% cultured in land-based farms. Over 75% of Tuna ($148m GVP) is derived from aquaculture (ranching) production and all oyster production ($112m GVP) is from aquaculture. The ninth largest group is comprised of aquaculture production (primarily of fish – barramundi) which have been grouped for reporting confidentiality reasons.

Table 6 below shows the top 11 fisheries (fishing & aquaculture) by volume and their relative percentage of total volume (FY19) and method of catch/production. This table highlights that the top 11 fisheries produce 78% of volume and the top 5 produce 65% of the total of domestic seafood production. The top fishery in Australia is aquaculture of salmonids which are produced almost exclusively in Tasmania. The second largest fishery, sardines, is predominantly utilised as feed for the tuna aquaculture industry in South Australia. At the end of the list, farmed prawns with a large expansion in Queensland have recently exceeded the production volumes of farmed barramundi and caught sharks/rays.

Table 6: Top 11 fisheries by method, value and volume and % of totals (2019)

Rank	Fishery	Method	GVP ($m)	% Val	Volume (t)	% Vol
1	Salmonids (farmed)	Cage culture	$890	28%	66,015	24%
2	Sardines	Purse seine	$30	1%	42,277	15%
3	Other finfish	Netting	$372	12%	62,280	22%
4	Prawns (wild-catch)	Trawl	$233	7%	17,640	6%
5	Rock Lobsters	Pots	$521	17%	8,002	3%
6	Tuna (farmed)	Cage culture	$137	4%	8,345	3%
7	Oysters (farmed)	Baskets	$137	4%	8,345	3%
8	Scallops	Dredged	$18	1%	6,615	2%
9	Barramundi (farmed)	Pond/cage/RAS	$91	3%	3,427	1%
10	Sharks/Rays	Netting/longline	$27	1%	5,031	2%
11	Prawns (farmed)	Pond/cage/RAS	$135	4%	6,740	2%
	SUBTOTAL		$2,591	82%	234,717	84%
	Australian F&A TOTAL		**$3,147**	**100%**	**280,830**	**100%**

b) Catch/production techniques & energy use

Energy use in F&A is a function of the catching or production 'method' utilised. In wild-catch fisheries, broadly, there are six main fishing methods employed across about ten identified broad catch fisheries in Australian waters, catching nearly 150 species. Of these six main methods, several have different subclasses of method, based on different configurations and designs, and depending on the species targeted.

Each of the fishing methods have specific techniques, but the majority utilise vessels – small and large – to access and deploy fishing gear, catch and sometimes process the catch on-board.

Fishing nets are responsible for the largest share of Australia's fish catches, and there are four main types of fishing gear that use netting: gillnets and entanglement nets, surrounding nets, seine nets, and trawls. Gillnets and entanglement netting techniques are 'set-wait-retrieve', or are free-floating, or dragged by boat or hand, whereas most surrounding nets, seine nets and trawls involve motorised vessels to position or lay nets or drag them through the water or over the seabed (trawls).

Other fishing methods include: hook and line (primarily from vessels to access fishing grounds) which include longlines, trolling and handlines; traps and pots (again, from vessels) which are usually 'baited' and include rock lobster, crayfish and crab traps/pots, a range of fish traps and trapping techniques; dredging – boat-towed heavy net configurations dragged across the seabed typically disturbing the sediments to dislodge scallops; and diving (snorkelling, SCUBA diving and hookah) undertaken by people who hand-collect/capture a range of species.

In aquaculture, fish, crustaceans and molluscs are grown in a range of systems. Australia's single largest fishery, the Tasmanian salmonid industry which produces half of Australia's seafood supply, along with tuna, kingfish, and barramundi operations in other States, all utilise sea cages situated in coastal waters, supported by vessels storing and providing fish feed, housing farm workers, and generating electricity for power.

In addition, fish, prawns, and lobsters are grown in extensive, aerated coastal earthen pond systems in Queensland, and NSW, situated adjacent ocean and estuarine seawater or freshwater, which is pumped onshore, used in ponds, and treated before exchange and discharge. Fish are also grown in intensive tank systems in Victoria, South Australia, Queensland and NSW and abalone in intensive flow-through tanks in Victoria, South Australia, and Tasmania and in 'ranches' situated in shallow coastal waters, in Western Australia.

Oyster farming, Australia's oldest aquaculture industry, operates in South Australia, Tasmania, New South Wales, Victoria, Queensland and Western Australia, utilising intertidal racks and baskets and subtidal floating lines and baskets. There is experimental oyster farming also being undertaken in the Northern Territory.

c) Fishing sector emissions scopes

For the **fishing sector**, GHG emissions are predominantly derived from **Scope 1** factors: fuel combustion in vessels, but also the release of refrigeration gases which have high GHG GWPs and emission factors (EFs).

The major Scope 1 factor fuel combustion is diesel[7] consumed by vessels to: travel to and from fishing grounds; undertake catching operations such as trawling and seining, net, longline, pot or trap setting and retrieval, or handlining; and to power onboard processing if applicable. There is also some petrol used in outboard motors on smaller fishing vessels, and tenders accompanying large vessels.

The fishing sector also utilises considerable volumes of refrigerant gases in their on-board freezers and chillers. These can contribute substantially to an operator's GHG emissions when the gases are accidently lost during operations or even deliberately vented to the atmosphere during maintenance. Estimates are that in fisheries with large on-board freezer requirements, these fugitive refrigerant emissions may contribute up to 20% of the total CO_2-e emissions for that enterprise.

Other Scope 1 emissions in the fishing sector may be derived from incineration of waste.

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[7] Typically reported as automotive diesel oil (ADO).

Scope 2 emissions (derived from electricity consumption) for most of the fishing sector, are relatively small (compared to Scope 1) but may be relevant where fishing operations utilise considerable amounts of electricity for post-harvest, onshore processing, refrigeration, and packaging.

Scope 3 emissions for the fishing sector are primarily derived from transportation of products (whole or processed). However, another source of Scope 3 emissions for many line and trap fisheries is the use of bait. The energy/emissions associated with capturing, processing, transporting, and storing bait utilised the catching process are each characterised as a Scope 3 emissions sources. In addition, the energy use/GHG emissions derived from storing seafood products in the supply chain, and markets/supermarkets, even cooking seafood in home or at restaurants can constitute Scope 3 emissions and some food production enterprises also include these within Scope 3 emissions estimates and the entire GHG footprint of the product.

A summary of the scopes of emissions, activities and GHG gases accounted for associated with Fishing operations are summarised in **Table 7** below.

Table 7: Summary of the scopes of emissions, activities and GHG gases accounted for associated with Fishing/Catching

Scope	Activities covered	GHG gases	Comments
Scope 1	Fuel use		
	Diesel	CO_2	Diesel engine fuel consumption
	Petrol	CO_2	Outboard motors
	LPG	CO_2	Used for cooking
	Non-combustion emissions		
	Refrigerant gas losses	CFCs	CFCs with high emission factors can contribute substantially to emissions profiles
Scope 2	Electricity consumption Onshore processing/ refrigeration	CO_2	Limited, unless operators have large processing facilities.
Scope 3	Bait consumed	CO_2-e	Emissions associated with catching, processing, storage, and use of bait.
	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.

d) *Aquaculture emissions scopes*

In the **aquaculture** sector, GHG emissions scope profiles vary considerably between the different culture/production systems utilised.

(1) *Land-based pond and tank systems*

Emissions derived from **land-based, pond and tank growout** systems (for fish, prawns, crayfish and other crustaceans, abalone and even algae/seaweeds) and post-harvest processing activities are predominantly **Scope 2**, derived from the considerable amounts of electricity utilised for water pumping and aeration, processing, and chilling. This electricity is predominantly supplied from main electrical distribution networks and is generated from various combinations of fossil fuels (coal & gas) and renewable generation (wind & solar) sources. Only a few aquaculture operators are utilising some renewable electricity generation, but many are reported to be considering purchasing more, for both cost and sustainability reasons.

Land-based pond growout operations also utilise diesel fuel for backup electrical generation in the event of mains electricity failures, as well as diesel and petrol for on-farm transport, all which generate **Scope 1 emissions**. However, these Scope 1 emissions are comparatively small when measured against the Scope 2 emissions.

The other source of **Scope 1** (direct) emissions from aquaculture is via 'fugitive' emissions from pond culture operations. The gases CO_2, CH_4 and N_2O are produced as a result of removing wetlands or coastal vegetation when creating aquaculture ponds. In addition, ponds also produce gases, derived from decomposition of vegetation, uneaten food, metabolic and waste products of the fish, crustaceans and molluscs being grown, and other microbial processes, which are released to the atmosphere. This is discussed further in section **(3)** below.

(2) Ocean cage systems

Emissions derived from **offshore ocean cage culture** of salmonids (Australia's largest aquaculture industry and fishery) as well as tuna, kingfish, and barramundi, are predominantly **Scope 1**. These operations, located in coastal and offshore waters often distant from land, utilise electrical power to drive aerators, feed blowers, lights, support for ROV, net cleaning and diving operations. However, the electricity for these activities is generated on attendant vessels moored alongside the cages, running generators operating on diesel fuel, therefore producing **Scope 1** emissions.

Ocean cage aquaculture production also consumes electricity (**Scope 2 emissions**) for hatchery operations and fish processing activities and may also consume gas (LPG) used for heating/cooking purposes (**Scope 1 emissions**). Unlike aquaculture hatchery operations, there are no emissions generated from the reproductive-growth stages of wild caught fish.

Feed also constitutes significant embodied **Scope 3 emissions**. Aquaculture feeds typically contain significant components of fish meal and fish oil, sourced from other directly targeted catch fisheries (anchovies), trash fish or from fish post-processing wastes (and processed to extract these components) processed animal proteins, as well as soybeans and grains, micro-nutrients, and vitamins. All of these components have emissions profiles created from their own supply chain processes which include their harvest, manufacture, transport, and supply to aquaculture operations. In the Australian southern bluefin tuna and kingfish ocean cage culture operations, fish are fed wild-caught sardines from southern Australian waters (Australia's second largest catch fishery by volume – but relatively low value), which are captured and then transported to land for freezing, or directly to the cage growout operations, where they are then fed to the carnivorous tuna.

Additionally, as fed aquaculture typically produces high-value seafood and products, markets may be diverse and distant, nationally, and internationally, and delivering the product to market requires considerable cold-chain logistics involving trucking, shipping and often air freight operations. These transport and logistics components of seafood products also represent significant **Scope 3 emissions** sources.

These **Scope 3** emissions which become part of the overall GHG footprint for fed species – salmonid, prawn, barramundi, tuna, kingfish, abalone, crayfish, and other finfish aquaculture operations – can constitute a significant component of an operation and its seafood product's overall GHG footprint. For some, these **indirect Scope 3** emissions can be even greater than their direct Scope 2 or Scope 1 emissions.

(3) Emissions from pond-based aquaculture

The methodologies used to estimate Australia's GHG inventory have evolved over time and continue to be refined as new information emerges, and as international practice evolves. The 2018 National Accounts Report did not account for wetlands derived emissions which included aquaculture. However, since then, Australia has prepared additional estimates for the voluntary reporting category of wetlands, including emissions for reservoirs and other constructed water bodies, certain ponded pastures, seagrass, tidal marsh removal, as well as for **aquaculture** and emergence/loss of mangrove forest (reported under forest categories).

The latest (2019) National Inventory report now includes improvements informed by the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (**IPCC 2019**[8]), and the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* (**IPCC 2013 Wetlands Supplement**[9]). Subsequently, in the National Accounts, aquaculture emissions are now calculated under the general category of LULUCF-derived activities, specifically relating to the methodologies for wetlands, but based only on '*fugitive*' emissions of N_2O.

(4) Aquaculture as carbon sequestration

Several coastal and oceanic aquaculture activities are attracting increasing attention for their roles in carbon sequestration (absorbing carbon from the atmosphere or oceans via biological activity) and creating carbon sinks. These so-called 'blue carbon' opportunities are being investigated and quantified for mangroves and seagrasses as well as for shellfish such as oysters and mussels.

Mangroves, seagrasses, and seaweeds can photosynthetically capture and sequester carbon in their biomass. Oysters and mussels can sequester carbon (as calcium carbonate) in their shells. This carbon may – depending on the fate of the organism – be permanently bound into substrates and accounted as sequestered carbon.

(a) Shellfish

Emissions derived from culture of shellfish (i.e. oysters, mussels, and other bivalves) are primarily small amounts of Scope 1, Scope 2 and Scope 3.

Scope 1 emissions are from vessel use and from low amounts of machinery use where combustion engines are used. Scope 2 emissions may be created as a result of electricity consumption used in processing, product handling, and upstream hatchery operations amongst other possible sources. Scope 3 emissions may be derived from transport of product as well as equipment and other materials used for growing operations.

Shellfish may also sequester carbon, which is incorporated into the animals' bodies but primarily in their shells.

Methods to assess carbon footprints for shellfish are complex, requiring a balance between calculation of the animal's respiration, shell calcium carbonate sequestration, and CO_2 release during biogenic calcification. Ecosystem interactions and differences between harvested and non-harvested bivalve populations also need to be considered.

Recent research has indicated that whilst shellfish may sequester amounts of carbon as their shells grow and absorb calcium carbonate, overall oysters and mussels may be **net carbon contributors**. However, recent studies[10] have also indicated that utilising direct measurements of methane and nitrous oxide, and estimated carbon dioxide fluxes via oxygen consumption rates, from feed production, gut fermentation, and manure management associated with the Eastern oyster, there is no greenhouse gas release from growing or transporting feed for oysters as they filter their food directly from the water. Any greenhouse gas release is from oysters themselves, via shell formation, respiration, or microbial processes in their guts, or by bacteria in the sediment metabolizing oyster wastes, or "manure." The study compared emissions with other food protein sources and therefore, any carbon dioxide produced from respiration was omitted from their overall estimate to match methods used for estimating livestock greenhouse gas production. In

[8] *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, prepared by the IPCC and adopted at its 49th Session in May 2019

[9] *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands,*

[10] Ray, Nicholas E., Timothy J. Maguire, Alia N. Al-Haj, Maria C. Henning, Robinson W. Fulweiler (2019), *Low greenhouse gas emissions from oyster aquaculture*, Environ. Sci. Technol. 2019, 53, 15, 9118–9127, at: https://doi.org/10.1021/acs.est.9b02965

addition, carbon dioxide release from shell formation was also not included as knowledge of the future use of the oyster shell is needed for accurate assessment of carbon release or sequestration.

The study demonstrated oyster aquaculture didn't release any methane and only negligible amounts of nitrous oxide and carbon dioxide, with all greenhouse gas release coming directly from the oyster itself. There was no difference in greenhouse gas release from microbial communities in the sediments beneath oyster aquaculture compared to bare sediments. The researchers did, however, observe increases of carbon dioxide production from sediments when an aquaculture site was in place for more than three years, but the carbon dioxide release returned to baseline levels after six years.

Ultimately, the study suggested oyster aquaculture appears to be a good alternative for protein production as it has less than 0.5% of the greenhouse gas-cost of beef, small ruminants, pork, and poultry in terms of carbon dioxide equivalents per kilogram of protein.

The oyster culture industry in Australia is a large industry within the overall aquaculture sector with significant oyster growing areas in coastal and intertidal areas of SA, TAS, NSW and smaller operations in VIC, QLD and WA. Mussels are cultured in TAS, NSW, VIC, SA, and WA. As indicated in the study referenced above, and other recent publications, 'offsetting' of oyster carbon emissions is relatively easy (compared with other protein) and may be a promising opportunity for shellfish farmers to improve the value and perception of their products.

Western Australian producer Harvest Road, has undergone a carbon offsetting process for its Leeuwin Coast oysters and mussels.[11]

A recent life cycle analysis (LCA) study for Aquaculture New Zealand compared the sustainability performance of Greenshell Mussels and Pacific Oysters farmed in New Zealand with other sources of dietary protein found that New Zealand mussels and oysters are among the animal protein sources with the lowest carbon footprint, and that NZ farmed shellfish have a lower carbon footprint than all other animal-derived protein sources, including farmed fish.[12]

(b) Seaweed & marine plants

The Australian seaweed industry is relatively undeveloped but is gaining considerable momentum as current aquaculture operations and new ventures explore the propagation and farming of seaweeds (macro and microalgae) for food (animal and human) and nutraceuticals. In addition, seaweed is also being investigated for use as a fuel for energy production (biofuels), for habitat restoration (nutrient removal) and also for carbon sequestration ('blue carbon') potentially to create carbon 'credits'.

In October 2021, the Clean Energy Regulator (CER) released a draft 'blue carbon' methodology under the Emissions Reduction Fund.[13] Whilst there is currently no mechanism to account for shellfish or seaweed/algal biomass as carbon sinks, it is expected that the *Carbon Credits (Carbon Farming Initiative—Tidal Restoration of Blue Carbon Ecosystems) Methodology Determination* will be a the first of an expanding range of potential blue carbon methodologies which will enable carbon from seaweeds and marine plants to be captured and accounted as Australian Carbon Credit Units (ACCUs).

(5) Summary of emissions sources and scopes - aquaculture

A summary of the scopes of emissions, activities and GHG gases accounted for associated with Aquaculture operations are summarised in **Table 8** below.

[11] See: https://www.harvestroad.com/leeuwin-coast-gets-green-light-with-australias-first-ever-certified-carbon-neutral-shellfish/
[12] See: https://www.thinkstep-anz.com/resrc/case-studies/a-life-cycle-assessment-of-nz-mussels-and-oysters-lca-aquaculture/
[13] See: https://consult.industry.gov.au/blue-carbon-method

Table 8: A summary of the scopes of emissions, activities and GHG gases accounted for associated with 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.

e) Use of GHG metrics

Energy & GHG *intensity* related metrics are increasingly important considerations used for benchmarks or comparators. These intensity related metrics may include total energy used or GHG emissions (as CO_2-e) per kilogram of fish, per fishery, or even per sector. Once calculated, these metrics can be utilised comparatively:

- between fishers or individual businesses (viz. between two businesses within a single fishery)
- between fisheries within the same commodity sector (viz., between two different prawn fisheries – Northern Prawn Trawl Fishery versus Spencer Gulf)
- between the same commodity with different catch methods (viz., coastal pelagic finfish caught by trawling, versus net fishing, or line fishing)
- between the same commodity with different sourcing (viz., wild-caught or farmed prawns), or
- between animal protein production industries (e.g. seafood versus beef, chicken, egg or pork production).

Moreover, assessments of GHG footprints are being developed within third-party certification schemes (e.g. Aquaculture Stewardship Council certifications and the Blue Tick certification mark). Carbon 'profiles' are forming significant factors in overall sustainability/ESG[14] assessments of businesses and industries, and in investment decisions.

f) Matrix of Australia's largest F&A activities and emissions scopes

The wide range of species, catching and growing methods in the Australian F&A sectors, which provides a complex matrix of energy usage and subsequent GHG emissions profiles. **Table 9** below provides an

[14] ESG = environmental, social and governance.

overview of Australia's largest fisheries (wild catch and aquaculture) by GVP, their catch/production methods and an indication of the emissions scopes and relative importance of the scope emissions.

The table also highlights that some species such as prawns, abalone, barramundi, are produced by aquaculture and fishing, which have quite different potential GHG emissions profiles and consequently the respective products, may have different carbon footprints.

Table 9: Summary matrix of major species, production methods and GHG scope emissions profiles[15]

Rank *(GVP)*	*Species/Fishery*	*Catch/ production technique (aquaculture and/or wild catch)*	*Aquaculture ($1.6b GVP) (51% GVP)*			*Wild catch ($1.58b) (49% GVP)*		
	Emissions type		**Scope 1**	**Scope 2**	**Scope 3**	**Scope 1**	**Scope 2**	**Scope 3**
1	Salmonids	Coastal cage culture	Medium	Low	High	n/a	n/a	n/a
2	Rock lobster	Traps/pots	n/a	n/a	n/a	High	Medium	Medium
3	Other finfish	Trawl, nets, line	Low	Medium	Low	High	Low	Low
4	Prawns	Trawl & pond culture	Low	High	High	High	Low	Low
5	Other crustaceans & molluscs	Traps, pond, coastal lines	Medium	Medium	Medium	Medium	Low	Low
6	Abalone	Hand caught, tank culture	Low	High	Medium	Medium	Medium	Medium
7	Tuna	Cage culture/ranching, line	High	Low	High	Med	Low	Low
8	Edible oysters	Coastal culture	Low*	Low	Medium	n/a	n/a	n/a
9	Other NEI (barramundi)	Pond culture, cage culture	Low	High	High	n/a	n/a	n/a

** can also be a sink - GHG profiles low/medium/high are meant to indicate relative GHG intensities. n/a = not applicable*

ii. Government energy use and GHG data capture & reporting for the F&A sectors

Energy use and GHG emissions data capture and reporting for all Australian industry, is currently conducted by several Commonwealth and State agencies.

The status of reporting of energy use and efficiency, and GHG emissions, relevant to the F&A sectors are detailed below.

a) National Greenhouse Accounts (National Accounts)

Currently, the emissions of the Australian F&A sectors have been calculated in the Australian National Greenhouse Accounts (NGA or '**National Accounts**') within the overall 'industry' aggregation of 'Agriculture, Forestry and Fishing' (**AFF**).

The most contemporary National Accounts, the *National Inventory Report 2019*, provides estimated 2019 (Scope 1 & 2) emissions for the entire AFF aggregation reported as **69.8 Mt CO_2-e.** This makes the AFF aggregation the third largest emissions profile in the Australia accounts.[16] On first reflection, this could be interpreted that the 'Fishing' industry (i.e. both the F&A sectors), presented as it currently is within the overall AFF aggregation, may be a substantial GHG emitter.

In addition, GHG emissions from energy production within sectors (i.e. GHG emissions from fixed and mobile equipment), are calculated separately. The *Agriculture, Forestry and Fishing* (AFF) industries which are included within 'Other Sectors' (component 1.A.4), have energy-related emissions (emissions from fixed and mobile equipment) of **7.8 Mt CO_2-e** (2018), based on a single aggregated estimate for diesel fuel consumed by the three industries.

[15] 2019-20 data sourced from Steven, AH, Dylewski, M and Curtotti, R 2021, Australian fisheries and aquaculture statistics 2020, Fisheries Research and Development Corporation, ABARES, Canberra, August.

[16] See: Commonwealth of Australia, National Inventory Report, The Australian Government Submission to the United Nations Framework Convention on Climate Change, Australian National Greenhouse Accounts, April 2021, at: https://www.industry.gov.au/news/australias-greenhouse-gas-accounts-for-2019

However, within this overall AFF aggregated estimate, Fishing (which *includes* aquaculture) has been estimated to constitute just 6% of the total AFF diesel fuel consumption (with Agriculture at 77% and Forestry at 17%). This 6% estimate was based on the relative volumes of diesel fuel for which excise rebates were claimed, as advised by the Australian Customs Service, over the period 1988 to 1994.

From then on (1995 through to the latest 2019 reports), the estimate of total diesel fuel use by the Fishing industry has been applied constantly at 6% of the total AFF industries consumption (i.e. the actual consumption for Fishing category is not recorded or reported). An actual consumption for Agriculture (and Forestry) is not recorded as part of the NGER Scheme. Therefore, as Agriculture diesel use has varied over time, the reported use by the Fishing industry (fishing & aquaculture) has also varied in parallel (as 6% of the total AFF number).

Nonetheless, based on these assumptions, the apportioned emissions for diesel use (Scope 1 emissions) within the Fisheries (fishing & aquaculture) sectors is **466 kt** or ~**0.5 Mt C02-e**

Table 10 below provides an extract from Table 3.25 Other sectors: recalculation of total CO_2-e emissions 1990 – 2018 for sector category 1.A.4.c Agriculture/**fisheries**/forestry (from National Inventory Report 2019, page 118) which indicates that based on the assumptions applied, diesel fuel consumption in the F&A sectors (commensurate with the entire AFF aggregation) has increased from 2000 to 2018 by over 70%.

Table 10: Extract from Table 3.25 Other sectors: recalculation of total CO_2 -e emissions 1990 – 2018 1.A.4.c Agriculture/fisheries/forestry

1.A.4.c Agriculture/fisheries/forestry (AFF)		
	2021 submission	
Year	Gg CO_2-e	Mt CO_2-e *rounded
1990	3,464	3.5
2000	4,484	4.5
2005	6,573	6.7
2010	6,205	6.2
2015	6,772	6.8
2018	7,759	7.6

(1) Fishing & Aquaculture (F&A) sectors only

The latest National Accounts reported (Scope 1) emissions for the **Fisheries** sector in **2019** was nominally **310 kt (**or **0.3 Mt CO_2-e)**, down from a **2018** peak of about **466 kt (or 0.47 Mt CO_2-e)**.

The reported (Scope 1 only) emissions for the **Aquaculture** sector in **2019** was nominally **397 kt** or (**0.4 Mt CO_2-e**), down from a **2018** peak of about **530 kt** (or **0.53 Mt CO_2-e**).

The National Accounts describe the data as Scope 1 and 2, however as it is calculated only on (diesel) fuel consumption, so therefore, are Scope 1 emissions only. Further detail on the F&A data also reported in the National Inventory by Economic Sector (NIBES) is presented in **section b)** below

It should also be noted that the National Accounts do not include Scope 3 emissions, as these emissions are reported as Scope 1 and included with the IPCC sectors in which the emissions occur.

Issues and inaccuracies with the data presented for the Australian Fisheries sector are discussed below.

b) NIBES

The Department of Industry, Science, Energy and Resources (DISER) also publishes the National Inventory by Economic Sector (NIBES). The NIBES reports greenhouse gas emission estimates by economic sector using the Australia-New Zealand Standard Industry Classifications (ANZSIC) codes, rather than by International Panel on Climate Change (IPCC) sector, as in the National Inventory Reports. It is effectively a disaggregation of the emission estimates in the National Inventory Report submitted to the United Nations Framework Convention on Climate Change (UNFCCC) each year.

The ANZIC economic sectors reported are:

- Primary industries: agriculture, forestry and fishing; and mining
- Manufacturing
- Electricity, gas, water and waste services
- Services, construction and transport
- Residential

The NIBES data is published annually (and the most contemporary published data is the 2019 report). NIBES data for aquaculture and fisheries was extracted and the methods and underlying assumptions reviewed.

The NIBES data for F&A indicates emissions for the two sectors in **2019** as presented in **Table 11** below.

Table 11: F&A sector emissions

Sector emissions (kt CO2-e)	2019	2018	2008
F&A Total	707	990	770
Aquaculture	397	530	410
Fishing	316	460	360

Figure 1 below provides a graphical representation of the National Accounts data for *direct emissions* for the F&A sectors (in kt CO_2-e), included within the Division A – Agriculture Forestry and Fishing (AFF) aggregation, for the years 2008 – 2019.

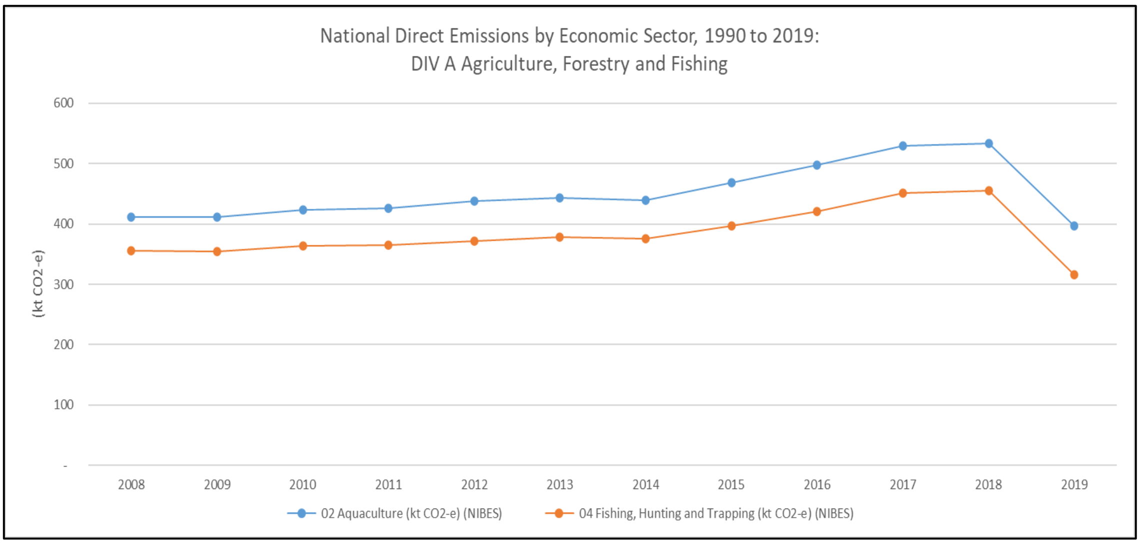

Figure 1: Direct emissions (Scope 1) for F&A sectors (within Division A: AFF reporting) reporting in the National Accounts (kt C02-e)

This NIBES data is calculated using two measures (each which have several assumptions associated with them):

Measure 1 (for both fisheries and aquaculture) – GHG emissions based on an estimate of diesel usage (direct, Scope 1 emissions) by the combined sectors; and

Measure 2 (for aquaculture only) – a further component of total GHG emissions, associated with N_2O 'fugitive' emissions has been calculated. The methodology is discussed further below.

(1) Fishing sector

(a) Measure 1 – Fisheries

NIBES Measure 1 uses the same assumptions as utilised in the National Accounts and assumes that fisheries (fishing and aquaculture) cumulatively account for six percent (6%) of the total diesel use in the agricultural sector.

An excerpt from the 2019 National Inventory Report regarding this calculation is provided below.[17]

> For the *1.A.4.c agriculture, forestry and fisheries category*, the AES present a single total figure for diesel fuel consumed in agriculture, fisheries and forestry. However, the types of equipment used by these industries vary quite widely (tractors, log skidders, fishing boats etc.), and therefore EFs for non-CO_2 gases also vary widely. It is assumed that the agriculture, fisheries and forestry industries account respectively for 77 per cent, 6 per cent and 17 per cent of total diesel fuel consumption by the sector as a whole. This estimate is based on the relative volumes of diesel fuel for which excise rebates were claimed, as advised by the Australian Customs Service, over the period 1988 to 1994 inclusive, and have been held constant throughout the period.

This assumption and the apportioning within the AFF aggregation has not changed, despite the initial data the assumptions were based on, now being twenty years old.

(2) Aquaculture industry

(a) Aquaculture emissions – Accounting methods

As indicated above, aquaculture emissions are estimated via Measure 1 and Measure 2.

Measure 1 emissions for aquaculture are allocated from within the entire Fisheries (fishing & aquaculture) estimate, and again, apportioned on the basis diesel fuel for which excise rebate claims over the period 1988 to 1994.

Measure 2 has only been applied to aquaculture in the NIBES calculations as a result of improved calculation methods for Land Use, Land Use Change and Forestry (LULUCF), which detail methods to determine 'fugitive' emissions from land changes under the *IPCC 2013 Wetlands Supplement*, which includes a method for activity-based net emissions calculation methods associated with seagrass, tidal marsh removal, as well as for **aquaculture** and emergence/loss of mangrove forest (reported under forest categories).

Wetlands (Component 4D) comprises emissions and removals from *wetlands remaining wetlands* and *forest land converted to wetlands*.

(b) Wetlands calculations and implications for aquaculture

Chapter 6 of Volume 2 of the National Inventory Report provides methods for all calculations of emissions associated with Land Use, Land Use Change and Forestry (LULUCF), including Wetlands (Component 4D) and specific methods for:

- '*Wetlands remaining wetlands*' (Source Category 4.D.1), and
- '*Land converted to wetlands*' (Source Category 4.D.2).

[17] 2019 National Inventory Report, April 2021 – Volume 1, page 115

Estimates under these two categories include CH_4 emissions from reservoirs and other constructed ponds, N_2O emissions from aquaculture use in tidal wetlands and net CO_2 emissions from removal of seagrass due to capital dredging, in addition to other vegetation-related sources of emissions and removals.

In addition, under *Wetlands remaining wetlands* (Source Category 4.D.1), there is a specific methodology for 'Aquaculture Production' (see **Figure 2** below).

Aquacultural production

The aquaculture (use) subdivision utilises the Australian production figures published annually by the Australian Bureau of Agriculture and Resource Economics (ABARES) in the Australian Fisheries and Aquaculture Statistics report. These statistics are available to the level of state or territory jurisdiction.

ABARES aquaculture production data are reported for various broad groups of animals, and the subgroups within those. The two groups of interest are "Fish" and "Crustaceans", both of which contain sub-groups that represent marine and/or freshwater species. Only production figures involving sub-groups that are mostly cultured in coastal wetland based facilities are included in this analysis. Therefore fish production data for salmonids, tuna and barramundi are included from "Fish", while prawns is the only sub-group reported from the "Crustacean" group. There are no other groups from the ABARES dataset reported here. Emissions are reported in Table H of the CRF tables.

Direct N_2O emissions were estimated using Equation 4.10 in the 2013 Wetlands Supplement. Note that quantities are expressed here in tonnes rather than kg, so that:

$$N_2O\text{-}N_{AQ} = F_F \bullet EF_F$$

Where $N_2O\text{-}N_{AQ}$ = annual direct N_2O-N emissions from aquaculture use; tonne N_2O-N yr^{-1}
F_f = annual fish production; tonne fish yr^{-1}
EF_f = emission factor for N_2O emissions from fish produced; 0.00169 tonne N_2O-N (tonne fish produced)$^{-1}$

N_2O emissions are reported as kilo-tonnes CO_2-e, based on the AR4 100 year N_2O global warming potential of 298.

Figure 2: Extract from National Accounts - approach to calculation of Aquaculture emissions

In addition, the National Inventory methodology notes state:

> *For the subdivision, N_2O from Aquaculture Use, ABARES aquaculture production data is available for the period 1991 to 2019 (ABARES: Australian fisheries and aquaculture production publications). These data are reported nationally and by state/territory and represent live-weight quantity of aquaculture product that is produced and marketed. The data generally excludes hatchery production. ABARES does not specify a level of uncertainty with its aquaculture and fisheries production figures. Uncertainty regarding annual finfish and crustacean production in coastal facilities is likely to be within the low to medium range.*

Figure 3 below provides a copy of the 'calculated annual emissions for aquaculture over the reporting period 1990 – 2019, presented in the National Inventory 2019 report.

Aquaculture production

Annual emissions for aquaculture over the reporting period 1990–2019 are shown in Table 6.62 below.

Table 6.62 Annual emissions calculated for aquaculture (use) within the *wetlands remaining wetlands* category

Year	Emissions (Gg CO_2-e)
1990	4
1995	10
2000	19
2005	23
2006	28
2007	31
2008	33
2009	36
2010	38
2011	40
2012	47
2013	46
2014	45
2015	52
2016	58
2017	55
2018	63
2019	65

Figure 3: Extract from the National Accounts – Annual emissions calculated for aquaculture (use) within the wetlands remaining wetlands category

Table 12 below provides a summary of Scope 1 & Scope 2 emissions reported for F&A NIBES 2018 – 2019.

Table 12: Summary of Scope 1 & Scope 2 emissions reported for F&A NIBES 2018 – 2019 (kt CO_2-e)

Sector	Direct Scope 1 (diesel fuel only)	Direct Scope 1 (N_2O fugitive emissions)	Indirect (Scope 2)	Total kt CO_2-e	Direct Scope 1 (diesel fuel only)	Direct Scope 1 (fugitive emissions)	Indirect (Scope 2)	Total kt CO_2-e
Year	**2019**				**2018**			
Fisheries	316	N/A	4.4	316	455	N/A	6.4	
Aquaculture	339.4	65.2	6.0	397	533	63	7.5	593

**N/A are included to indicate that refrigerant loss emissions are not currently captured in the NIBES data collection*

(3) Scope 2 emissions

(a) <u>Top-down approach (NIBES)</u>

There is a broad allocation of Scope 2 emissions (indirect emissions from purchased electricity consumption) for the entire Agriculture sector. However, they are not specifically disaggregated for the F&A sector.

Taking a similar approach to fuel use, a nominal 6% allocation of the total Scope 2 emissions from electricity use for the F&A sectors, indicates a total of 6.48 Mt CO_2-e. However, intuitively, aquaculture will have a higher proportion of that electricity use than fishing and in particular, land-based aquaculture will constitute a high percentage of this allocation, due to the intensive use of electricity for powering water pumping, aeration for hatcheries and grow-out operations predominantly, and freezing and refrigeration.

By comparison, ocean cage aquaculture's use of purchased electricity is limited to hatchery operations (for water pumping, aeration, lighting, HVAC) and processing operations,

(b) Bottom-up approach (industry data)

Industry and published information within scientific publications was utilised to attempt a 'bottom-up' estimation of Scope 2 GHG emissions in the F&A sectors from electricity use.

To calculate total emissions, information regarding GHG intensity (from electricity only) per kilogram of seafood produced, was utilised, and then multiplied by total production volumes of the top 11 fisheries (in kilograms).

The GHG intensity (from electricity only) per kilogram product (in kg CO_2-e per kg of product) varied considerably.

The sardine fishery GHG intensity (from electricity only) was 0.3 kg CO_2-e per kg, whilst most other fishing operations (prawns, sharks/rays, rock lobster, oyster, and other finfish) were 0.8 kg CO_2-e per kg, whilst tuna was 1.6 kg CO_2-e per kg predominantly reflecting the relative amounts of electrical use for onshore refrigeration/freezing.

Salmonid production electrical use was within the same range (0.6 kg CO_2-e per kg) predominantly consumed for onshore hatchery and processing operations.

However, farmed barramundi is a substantial electricity consumer with an electricity use GHG intensity of 5.6 kg CO_2-e per kg produced, and farmed prawns also at 5.6 kg CO_2-e per kg produced.

However, by total GHG emissions volumes from electrical consumption, and reflecting total volumes of seafood produced, farmed prawns produced 43 kt, farmed salmon 40 kt, and farmed barramundi 19 kt of CO_2-e, but the largest sector was the Other Finfish industries with nearly 50 kt, whilst having a relatively low GHG intensity, but reflecting the large volume of fish caught (and subsequently processed, chilled and frozen). The electricity generation method (e.g. renewable or fossil-fuel) may also have an impact on the GHG intensity. For example, a land-based facility in Tasmania may have a lower GHG intensity compared to an identical facility in NSW due to the higher percentage of renewables within the Tasmanian electricity network.

(4) Scope 3 emissions

Scope 3 GHG emissions are those emissions generated in the wider economy because of the activities of an enterprise/facility, but from sources not owned or controlled by that enterprise/facility. Some Scope 3 examples are emissions:

- from sourcing and production of *purchased input materials*
- from or associated with *transportation of purchased inputs*, fuels, services, *and sold products*, and
- associated with the use of sold products.

However, Scope 3 emissions are currently not disaggregated and reported under the government GHG reporting schemes.

Nonetheless, Scope 3 emissions are very important for the F&A sectors and are discussed in detail in **section d** below.

c) Fuel consumption and reporting

The key input for this calculation is the quantity of fuel reported against the entire AFF sector in the Australian Energy Statistics. As discussed above, the primary measure of GHG emissions in the Australian F&A sectors is derived from the percentage of fuel (primarily diesel) used by these subsector industries.

However, this data, has been based on historical fuel tax rebate data and ongoing apportionment of fuel use within the overall AFF aggregation, also based on ABS input-output models (which have also apportioned total Agriculture fuel use to Fishing and Aquaculture activities).

To try to seek further and better detail and data for fuel use, we approached the ATO – as current custodian of diesel fuel tax rebate claims – for access to its databases. Findings from this review are provided below.

(1) ATO Fuel Tax data

After assessing the metrics in the NIBES reporting for fuel use, we identified the *Fuel Tax Credits Scheme* currently administered by the Australian Tax Office (ATO) as possible alternative source of fuel use data. By extracting ATO statistics on Fuel Tax Credits, together with historical fuel excise rates, we derived an estimate of fuel use data for fisheries and aquaculture over an historical time series.

Our investigations revealed that for the period of 2008 – 2018:

- fuel tax credit scheme claims (and by extension fuel use) for Aquaculture were much lower than those for Fishing
- calculation of GHG emissions based on fuel use derived from the Fuel Tax Credit Scheme (FTCS) data indicate that direct emissions from Aquaculture are significantly lower than direct emissions from Fishing.

Figure 4 below provides a graph of the implied fuel use for the F&A sectors, derived from the FTCS data.

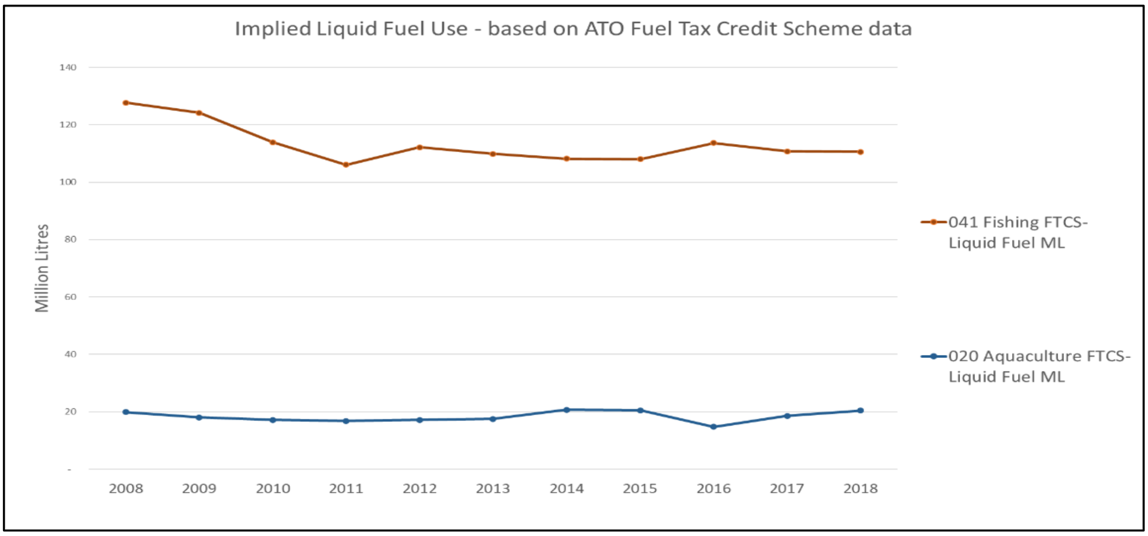

Figure 4: Implied liquid fuel use for F&A sectors, derived from published ATO fuel tax credit scheme data

However, these trends appear to be contrary to the fishing and aquaculture production trends and whilst the fuel tax credit scheme data are reliable in terms of representing actual tax claims made against eligible fuel use, we have some hesitation in accepting the data uncritically.

Aquaculture production has increased significantly over the past decade, while the FTCS data show Aquaculture claims (and by implication fuel use) to have remained relatively constant at approximately 20 million litres per year.

The implications from this are:

- the large aquaculture industry companies using diesel fuel (salmon & tuna) may have their FTCS claims recorded under another industry classification (not Aquaculture), or
- the large production increases have been accompanied by no significant increases in fuel use.

Another issue is that FTCS data does not include fuel purchased outside Australia. Some fishing vessels refuel outside of Australia and therefore their fuel use will not be captured in Fisheries data.

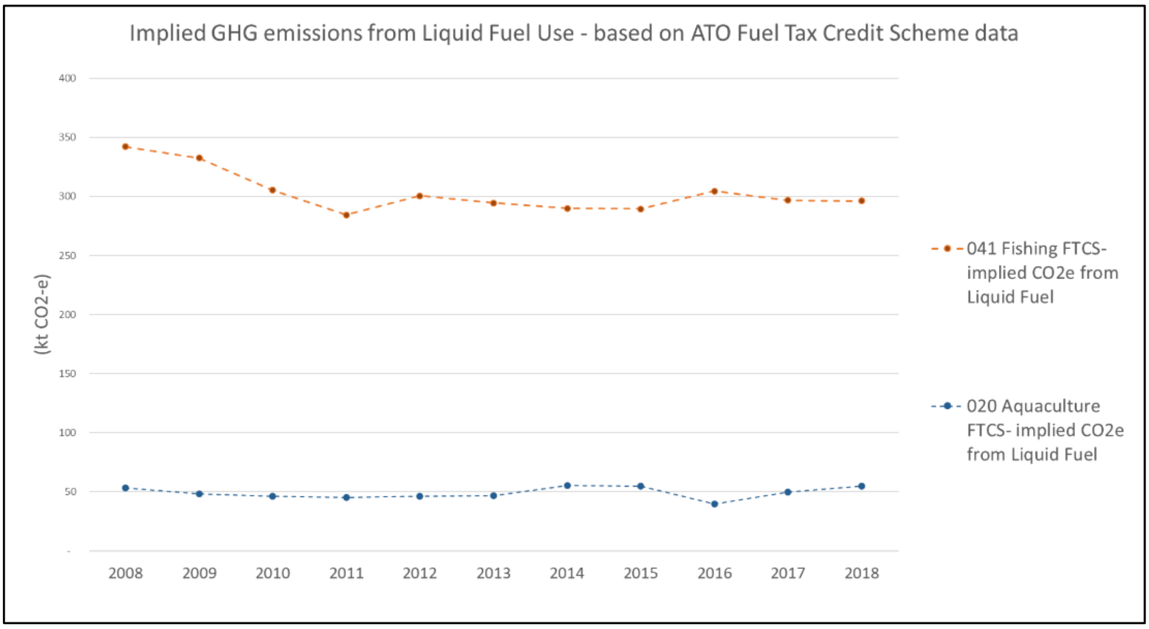

Figure 5: Implied GHG emissions from liquid fuel use for F&A sectors, derived from published ATO fuel tax credit scheme data

The ATO uses the 5-digit Business Industry Code (BIC) as a guide to assist taxpayers to select their most appropriate industry category for their business activity.

> A business industry code (BIC) is a five-digit code you include on relevant tax returns and schedules that describes your main business activity.
>
> BICs are derived from the Australian and New Zealand Standard Industrial Classification (ANZSIC) codes and have been simplified for tax return reporting purposes.

Nonetheless, historically it has not requested more detailed information than the three-digit BIC and therefore is provided with and only produces data aggregated at the three-digit level (e.g. 041 = Fishing, 020 = Aquaculture) as indicated in **Figure 5** above.

As illustrated in **Figure 6** and **Figure 7** that follow, reporting for multiple industries are aggregated to a single descriptor.

04111 Rock Lobster Fishing	**04112 Crab Potting**
04111 Crayfish potting, marine or coastal	04112 Crab fishing or potting
04111 Rock lobster fishing and processing aboard vessel at sea	04112 Saltwater crab fishing
04111 Rock lobster fishing or potting	
04111 Rock lobster fishing, marine or coastal	**04191 Abalone Fishing**
04111 Rock lobster potting	04191 Abalone fishing
04111 Saltwater crayfish fishing	04191 Abalone/paua fishing
04111 Saltwater crayfish fishing and processing aboard vessel at sea	04191 Pearl diving
04120 Prawn Fishing	**04192 Marine Fishing n.e.c.**
04120 Prawn fishing	04192 Beche-de-mer fishing
04120 Prawn fishing and processing aboard vessel at sea	04192 Crustacean fishing and processing aboard vessel at sea (except crayfish, lobsters or prawns)
04120 Scampi fishing	04192 Cuttlefish fishing
04130 Line Fishing	04192 English perch fishing - marine
04130 Bottom long line fishing	04192 Kelp collecting or gathering
04130 Fish trolling, marine or coastal	04192 Marine water fishery products gathering
04130 Inland hook fishing	04192 Marron fishing
04130 Inland line fishing	04192 Mollusc fishing and processing aboard vessel at sea (except abalone fishing)
04130 Line fishing	04192 Ocean or coastal water fishery products gathering (except abalone fishing)
04130 Line fishing, marine or coastal	04192 Octopus fishing
04130 Ocean trolling	04192 Oyster catching (except from cultivated oyster beds)
04130 Squid jigging	04192 Oyster fishing (except from cultivated oyster beds)
04130 Surface long line fishing	04192 Oyster shell gathering
04140 Fish Trawling, Seining and Netting	04192 Pearling (except pearl oyster farming)
04140 Beach seine fishing 04140 Beach seining	04192 Saltwater mollusc fishing (except from cultivated oyster beds and abalone fishing)
04140 Beach seining, fishing	04192 Scallops dredging
04140 Bottom gill netting, fishing	04192 Seashell collecting
04140 Bottom gillnetting	04192 Seaweed - algae - collecting or harvesting
04140 Bottom pair trawling	04192 Shellfish collecting (except abalone fishing)
04140 Bottom single trawling	04192 Spat catching
04140 Danish seine fishing	04192 Sponge gathering
04140 Danish seining	04192 Trepang fishing
04140 Danish seining, fishing	04192 Trochus shell fishing
04140 Drag net fishing	04192 Turtle hunting
04140 Drift net fishing	04192 Whaling
04140 Finfish trawling	**04199 Other Fishing n.e.c.**
04140 Finfish trawling, marine or coastal	04199 English perch fishing (except marine)
04140 Gill net fishing, marine or coastal	04199 Freshwater crayfish fishing
04140 Lampara netting, marine or coastal	04199 Freshwater eel fishing
04140 Midwater trawling, marine or coastal	04199 Freshwater fishing
04140 Pair trawling	04199 Freshwater whitebait fishing
04140 Purse seining	04199 Golden perch fishing
04140 Set net fishing, marine or coastal	04199 Lake fishing
04140 Set netting	04199 Murray cod fishing
04140 Set netting, fishing	04199 Mussel fishing
04140 Surface netting	04199 River fishing
04140 Surface netting, fishing	04199 Yabby fishing (except farming)

Figure 6: Fishing industry reporting within Business Industry Codes, as applied to ATO Fuel Tax Credit Scheme data

02011 Oyster Farming	**02039 Other Onshore Aquaculture**
02011 Cultured pearl production	02039 Abalone farming
02011 Oyster farming	02039 Balmain bug farming or breeding
02011 Oyster farming - rack	02039 Crustacean breeding or farming, pond or tank (except lobster)
02011 Oyster fishing from cultivated oyster beds	02039 Crustaceans or molluscs breeding or farming, pond or tank (except lobster)
02011 Pearl farming - aquaculture	02039 Fish breeding or farming, pond or tank (except lobster)
02011 Pearl oyster farming	02039 Fish hatchery operation (except lobster)
02011 Pearl oyster farming - rack	02039 Freshwater crayfish farming or breeding
02019 Offshore Longline and Rack Aquaculture n.e.c.	02039 Goldfish breeding
02019 Aquaculture (except lobster and oyster farming or onshore or caged aquaculture)	02039 Marron farming or breeding
02019 Aquatic animal farming (except lobster and oyster farming or onshore or caged aquaculture)	02039 Ornamental fish farming
02019 Mollusc (except oyster) breeding or farming - offshore - longline or rack	02039 Paua farming - pond
02019 Mussel farming - longline	02039 Prawn farming - pond
02019 Offshore longline or rack aquaculture (except oyster)	02039 Prawn farming or breeding - pond
02019 Paua farming - longline or rack	02039 Salmon farming - pond or tank
02019 Seaweed farming - longline or rack	02039 Salmon hatchery operation
02019 Shellfish farming (except oyster farming)	02039 Trout breeding or farming - pond or tank
02020 Offshore Caged Aquaculture	02039 Trout farming - pond or tank
02020 Finfish farming - caged	02039 Trout hatchery operation - pond or tank
02020 Salmon breeding or farming - caged	02039 Tuna farming - pond or tank
02020 Salmon farming - caged	02039 Yabbie farming - pond or tank
02020 Trout farming - caged	02039 Yabby farming - pond or tank
02020 Tuna farming - caged	
02031 Lobster Farming or Breeding	
02031 Lobster farming or breeding	
02031 Saltwater crayfish farming or breeding	

Figure 7: Aggregation of Aquaculture industry reporting within Business Industry Codes, as applied to ATO FTCS data

However, over the last few years this has been updated, and the ATO now collects data at the four and five-digit level BICs.

(a) *BIC five-digit level data analysis*

The ATO provided the project with more detailed data for the past three financial years (2019-20, 2018-19 and 2017-18) presented within four-and five-digit level BICs, providing for much greater energy information for the many sub-categories of fisheries (under the four- and five-digit level industry subsectors) to be assessed. Unfortunately, this level of data was not available back further than this period.

Figure 8 below provides a breakdown of FY20 – FY18 implied fuel use derived from the ATO five level BIC data.

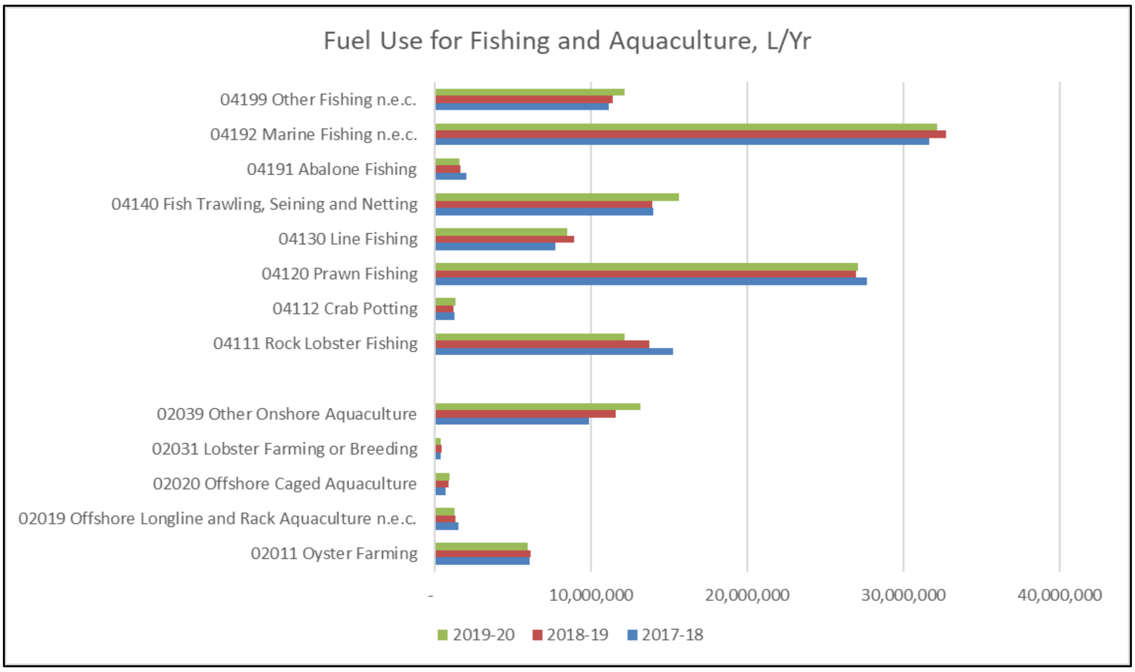

Figure 8: Implied diesel use for F&A sectors, derived from supplied ATO fuel tax credit scheme data

This data provides the following indications:

- Whilst the 5-digit BIC is useful, the level of specialisation in the fishing (and aquaculture) sectors require reporting companies to use further 6-,7-, or even 8-digit BIC levels to derive meaningful data. For example, business industry code '04140 Fish Trawling, Seining and Netting' is a significant liquid fuel consumer, estimated at 14 – 15 million litres per year, but encompasses a further 25 industry subsectors, including beach seining, bottom gill netting, bottom trawling, Danish seine fishing, drag netting drift netting. Similarly, the five-digit BIC's '04130 Line Fishing', '04192 Marine Fishing n.e.c.' and '04199 Other Fishing n.e.c.' also have many subcategories.
- Together the three largest 5-digit BIC classifications represent approximately 50% of fuel tax credit claims and liquid fuel consumption within the fisheries sector but is currently unable to be discerned at a finer level. Similarly, for the category 02039 Other Onshore Aquaculture, which includes pond aquaculture of barramundi and prawns (the two largest onshore aquaculture industries) data at this industry level is currently not available.
- The 2008 – 2018 data indicates that the volume of fuel use for aquaculture has remained relatively constant over the period, while production has increased substantially, predominantly from offshore cage culture of salmonids (salmon and ocean trout). From FY18 to FY20, the reported BIC 02020 Offshore Caged Aquaculture FTCS claim increased 34% from 715,000 to 957,000 litres per annum, but the total FY20 volume represents just 0.6% of the total Aquaculture FTCS claims, whilst producing just over 80% of total Australian Aquaculture production. **This disparity indicates that FTCS claims for the sector are not being captured under the appropriate industry category, and that fuel consumption for this major industry and for aquaculture overall is being considerably under-reported**. It also raises the question of whether the FTCS claims are being recorded under another related category (in fishing – e.g. 04199 Other Fishing n.e.c.) or even in another industry category altogether, such as marine transportation.
- The ATO FTCS data for the relatively small BIC defined industry sectors such as rock lobster, prawn, crab, and abalone fishing allow for assumptions about fuel use and corresponding GHG emissions profile to be made with reasonable confidence. For example, for the wild catch prawn trawling industry, direct fuel combustion emissions represent 66% of its total carbon profile.
- Whilst the FTCS data may be a good proxy for fuel use of the Fishing sector and estimating the GHG emissions profiles, it has limited utility for the Aquaculture sectors. The Fishing sector's fuel emissions represent about half and other transport related emissions another 11% of total

emissions. These are the two largest contributors to Fishing's total emissions profile, so more accurate data on fuel use will yield good returns for estimating and managing the sector's emissions. However, for aquaculture, direct fuel use is currently estimated at about 10% of its total estimated emissions profile but may however, be substantially under-reported as highlighted above. So, unless, the reporting issues can be resolved, the FTCS may be of limited use for emissions tracking in the Aquaculture sector.

- This more granular Fuel Tax Credit Scheme data allows some cross-industry comparisons of GHG metrics, in combination with ABARES fisheries and aquaculture statistics. Unfortunately, the ABARES Fisheries Statistics can supply data only to the 2017-18 financial year, unlike the ATO data which goes to the 2019-20 financial year, so we can only usefully use the 2017-18 data.[18]

d) Scope 3 emissions

As outlined in the introduction to this section, determining Scope 3 – Indirect Emissions (other than scope 2) generated in the wider economy because of the activities of an enterprise/facility, but from sources not owned or controlled by that enterprise/facility – can be complex. Scope 3 examples GHG emissions can include those associated with sourcing and production of purchased input materials, from or associated with transportation of purchased inputs, fuels, services, and sold products, and even emissions associated with the 'use' of sold products. The latter – for the food industries – can include preparation and cooking of the products.

As also indicated, Scope 3 emissions are currently not disaggregated, measured, or reported in the NIBES or National Accounts and therefore are primarily calculated individually by companies (or industries), or by third parties/NGOs.

(1) Fishing sector

As indicated above, Scope 3 emissions for the fishing sector are primarily derived from transportation of products (whole or processed). However, another source of Scope 3 emissions for many line and trap fisheries is the use of bait. The energy/emissions associated with capturing, processing, transporting, and storing bait utilised the catching process are each characterised as a Scope 3 emissions sources.

In addition, the energy use/GHG emissions derived from storing seafood products in the supply chain, and markets/supermarkets, even cooking seafood in home or at restaurants can constitute Scope 3 emissions and some food production enterprises also include these within Scope 3 emissions estimates and the entire GHG footprint of the product.

An assessment of Scope 3 emissions in the sector indicated:

- **Bait** is utilised in the Rock Lobster, parts of the other Finfish, and parts of the Shark/Ray fishing operations. However, GHG intensity for bait in the finfish and shark/ray fisheries is relatively low (~0.8 kg CO_2-e per kg of seafood caught) and therefore is not a significant contributor to the overall footprint of these industries. In the Rock Lobster industry, it constitutes about 7% of the total of that industry's GHG profile.
- **Transport (of product)** is a ubiquitous source of emissions across the entire fishing sector and is generally proportional to the volume of the products caught, but also to the distance it is transported. Given that the considerable distances required to transport product around a country the size of Australia, and that much of our high-value product is exported, transport emissions intensities are a relatively high contributor to the overall carbon footprints of most fisheries and fish products. Rock lobster has the highest per kilogram emissions intensity for transport (~5 kg CO_2-e per kg), due to most of the product being air freighted to northern Asia, and product transport

[18] The latest ABARES Fisheries Statistics 2021 report is expected to add two more years of production statistics, and thus allow three years of comparison with Fuel Tax Credit Scheme data.

constitutes nearly 45% of the total carbon footprint of Rock Lobster industry. Catches of about 62,000 tonnes of Other Finfish whilst having a relatively low transport GHG intensity (~1 kg CO_2-e per kg), derive transport emissions of about 62 kt CO_2-e which represents about 22% of the industry's total footprint.

(2) Aquaculture sector

As indicated earlier in **section d**, Scope 3 emissions for the aquaculture sector are primarily derived from feed inputs and transportation of products (whole or processed). In addition, the energy use/GHG emissions derived from storing seafood products in the supply chain, and markets/supermarkets, constitute Scope 3 emissions. Even cooking seafood in home or at restaurants constitutes Scope 3 emissions and some seafood production enterprises in Australia (notably salmon and Patagonian toothfish), also include these within Scope 3 emissions estimates and the entire GHG footprint of their products.

An assessment of Scope 3 emissions in the Aquaculture sector indicated:

- **Feed** inputs represent a significant component of the overall carbon footprints of the fed aquaculture industries. The highest emissions intensity for feed inputs is in the farmed tuna industry (12 kg CO_2 per kg product) which uses wild-caught sardines, which have an embodied carbon footprint from their capture process and storage, prior to being fed to the tuna.[19] Farmed prawns have the next highest feed GHG intensity at 6 kg CO_2 per kg product, with salmonids and farmed barramundi at 4.6 kg CO_2 per kg product. These feeds are derived from fish meal and fish oil, and pulses (soy) and grains (wheat) and other additives each which have their own carbon footprints for production, which are embodied in the overall aquaculture feed GHG emissions profiles. The GHG emissions for the salmonids industry is over 300 kt CO_2-e, whilst tuna is 100 kt CO_2-e, farmed prawns 40 kt CO_2-e, and farmed barramundi nearly 16 kt CO_2-e. **Significantly, the contribution of feeds to the entire Australian seafood GHG emissions profile is over 470 kt CO_2-e and represents the largest single contributor to GHG emissions, even greater than that of fuel combustion**.
- **Transport** in the aquaculture sector – like the fishing sector – is a ubiquitous source of emissions and is generally proportional to the volume of the products caught, but also distance it is transported. For fed aquaculture, the transport of feeds also provides additional Scope 3 emissions. For salmonids, transport constitutes about 66kt CO_2-e (~12%), for tuna – which has a relatively higher product transport emissions intensity (~2 kg CO_2-e per kg) due to the product being shipped to northern Asia – produces 16 kt CO_2-e emissions, or about 15% of the industry's total emissions. Farmed prawns transport related emissions are about 6.7 kt (6.6% of total carbon footprint) and farmed barramundi 3.4 kt CO_2-e (7.4% of total carbon footprint).

e) Summary of emissions profiles of Australian F&A sectors

A compilation of both top-down data provided in the NIBES, and bottom-up industry and anecdotal data, has enabled a summary of likely GHG emissions for the entire F&A sectors and major industries within them to be prepared.

Table 13 and **Table 14** below provide a summary of the emissions profiles of the top 11 F&A seafood industries/species, assessed within:

- Scope 1 (fuel combustion; refrigerants; N_2O emissions)
- Scope 2 (Purchased electricity)
- Scope 3 (Feed & bait, transport).

[19] The sardine fishery itself has a relatively low carbon footprint, it increases significantly when sardines are caught, processed, stored and then fed to farmed tuna.

Processing emissions estimated separately, were allocated for fishing as Scope 3 emissions and for aquaculture as Scope 2 emissions.

Key highlights from this compilation and overview include:

- The GHG emissions of the Australian F&A sectors as represented by the top 11 fisheries constituting 82% of all Australian seafood production (2019-20) is estimated to be approximately **1.5 Mt CO_2-e**. This equates to an **average GHG intensity of 6.5 kg CO_2-e per kg of Australian produced seafood** from fishing and aquaculture. Whilst noting that this is greater than twice the NIBES reported emissions for the F&A sectors it should also be noted the NIBES data does not include provisions for Scope 2 and Scope 3 emissions at the F&A sector level, and for parts of the sectors these components can be the majority emissions sources.
- Of the overall emissions in the F&A sectors, aquaculture constitutes 900 kt CO_2-e or 59% of the emissions for the aquaculture industries included, whilst fishing produces 625 kt CO_2-e (41% of the total). Average **GHG intensity** for **fishing** was estimated at nearly **4.4 kg CO_2-e per kg** of catch, whilst average intensity for **aquaculture** was estimated at **9.7 kg CO_2**-e.
- Of the total emissions profile of both sectors, **purchased feed** (and bait) constituted the highest GHG emissions component of the entire profile, at just over 470 kt CO_2-e (31%), followed by (diesel) **fuel use** at just under 390 kt CO_2-e (25%) and **transport** about 245 kt CO_2-e (16%).
- By production volume, the largest industry contributor to the GHG emissions profile is the **salmonids industry** with 560 kt CO_2-e constituting 37% of total emissions and produces 28% of volume and 24% in value of all domestic seafood production. The next most significant are the **Other Finfish** industry group with 280 kt CO_2-e (~18%) and produces 22% of volume and 12% by value of all domestic seafood production, **tuna farming** which produces 150 kt CO_2-e (nearly 10%), **prawn trawling** 118 kt CO_2-e (~8%), and **prawn farming** 102 kt CO_2-e (7%).
- In terms of emissions intensities, **farmed tuna is the highest GHG intensity product**, with nearly 18 kg CO_2-e per kg of product produced, thanks to a combination of the fuel used to catch the juvenile fish, GHG intensive feed inputs, and high transport costs to deliver products to distant export markets.[20] The next most GHG intensive product is **farmed prawns** with 15.2 kg CO_2-e and **farmed barramundi** at 13.5 kg CO_2-e per kg of product produced. **Rock lobster** is the next most GHG intensive product at just over 11 kg CO_2-e per kg, and farmed **salmon** at 8.5 kg CO_2-e per kg of fish produced. Industry leader Tassal estimates a total carbon footprint of its edible salmon meat of 12kg CO_2-e/kg which accounts for full post processing storage, transport, and cooking. [21]
- Significantly, **the predominant emissions for the F&A sectors are Scope 3**, totalling 52% of the total profile, of which 45% are derived from feed/bait, transport, and processing related costs,[22] followed by Scope 1 emissions (fuel and fugitive emissions from refrigerant gases and N_2O) representing 31%.

(1) Fishing highlights

- The **fishing industry contributes about 41% of the F&A sectors' total emissions** profile. Nearly half is Scope 1 emissions, principally fuel combustion, followed by Scope 3 emissions dominated by transport and secondary processing. Scope 2 emissions, electricity was the third highest aggregation. However, as 'processing costs' are captured in both Scope 2 and Scope 3 emissions profiles, the **overall ranking of emissions for the fishing industry** are: 1) **fuel** combustion 2) **processing** and 3) **transport** (of primary and secondarily processed products).
- An estimate of total GHG emissions for the Australian fishing sector indicates that the top six industries examined (Sardines, Other Finfish, wild-caught Prawns, Rock Lobsters, Scallops and

[20] Tuna intensity is even higher if the GHG emissions of sardine fishing are included.
[21] Industry leader Tassal estimates total carbon footprint is 12kg CO_2-e/kg edible salmon meat, from Tassal's 2021 Sustainability Report.
[22] Noting that estimates for these Scope 3 emissions are very high level and may vary considerably within sectors and therefore the overall number.

Sharks/Rays) produces approximately 625 kt CO_2-e with an average GHG intensity of nearly **4.4 kg CO_2-e per kg**. The largest contributors are the Other finfish, Prawn trawling, and Rock lobster catching industries. Within the overall fishing sector, fuel consumption constitutes 46% of total emissions and along with some refrigerant loss emissions (3%) make up Scope 1 emissions which constitute nearly half of all emissions associated with fishing.

- Within these fishing industries, for wild catch prawn trawling Scope 1 emissions represent 66% of the industry's total emissions, and scallops 64%, highlighting the fuel combustion driven nature of their carbon footprints. Expectedly, Scope 3 emissions from transport (23%) represent the other major contributor to the carbon footprints of the fishing industries. For the Rock Lobster industry, transport emissions plus the purchase of bait, constitute 52% of the fishery's GHG profile. For sharks and rays, which also have some bait purchase related emissions and transport, Scope 3 emissions represent 36% of the fishery's total carbon footprint. Other finfish transport emissions (whilst having a small component of bait – but not calculated) constitutes 22% whilst prawn trawling 15% of total emissions.

(2) Aquaculture highlights

- The **aquaculture industry broadly contributes 59% of the total F&A sectors' total emissions** profile. An overwhelming proportion of this (66%) is characterised as Scope 3 emissions, predominated by feed (principally for salmonids), which represent the single largest GHG emissions contribution from the entire Australian seafood production. It is also relevant to note that much of the emissions associated with these feeds is embodied outside of Australia, and therefore are not captured in our National Accounts framework or reporting. Nonetheless, as the fish grow-out in Australia, the CO_2 and methane emissions from the feed application, their respiration and growth are theoretically part of the emissions data framework but are currently not calculated or reported in the National Accounts.
- Consistent with the feed emissions profile outlined above, the salmonids industry is the largest GHG emitter by production volume in Australia, with a nominal emissions profile of 0.56 Mt CO_2-e, and with feed constituting 54% of the industry's emissions. Similarly, tuna, with a total emissions profile of 150 kt CO_2-e, has high GHG embodied feed component of 100 kt CO_2-e representing 67% of the industry's total emissions and making farmed tuna with a GHG intensity of nearly 18 kg CO_2-e per kg of fish produced. Somewhat different to the feeds utilised by the salmonid, prawn and barramundi farming operations which is manufactured from products produced outside of Australia, the tuna industry relies on Australia's second largest fishery by volume – sardines – as feed, and the GHG emissions embodied in this fishing activity, plus the emissions generated when sardines are processed, stored/refrigerated and then fed to farmed tuna, contributes to the high GHG intensity of tuna production, which occurs and is nominally accounted within the Australian GHG accounting framework and National Accounts.
- The emissions profiles of the prawn and barramundi aquaculture industries are characterised by the Scope 2 emissions (purchased electricity) for production and processing, constituting 45% of the total emissions, and feeds (Scope 3) which constitute 34% and 39% respectively of total GHG emissions. Whilst Scope 3 emissions are not part of the Australian reporting framework (as they are reported instead as Scope 1 emissions for the activities in which they occur) for the barramundi and prawn farming industries which represent nearly half of the non-salmonid aquaculture sector, Scope 2 emissions of 67 kt CO_2-e – 10 times those of Scope 1 emissions (fuel combustion) are currently not reported at this level of disaggregation– whilst Scope 1 are.

Table 13: Summary of GHG emissions Australian F&A sectors

Fishery/ species (Ranked by production volume)	Production method	Sector Fuel Usage (L)*	Fuel		Refrigerants		Purchased Power		Purchased Feed/ Bait		Processing		Transport		Aquatic N2O		Totals		% of total F&A	Notes
			kg CO2-e per kg	Sector (t CO2-e)	kg CO_2-e per kg	Sector (t CO2-e)	kg CO2-e per kg	Sector (t CO2-e)	kg CO2-e per kg	Sector (t CO2-e)	kg CO2-e per kg	Sector (t CO2-e)	kg CO2-e per kg	Sector (t CO2-e)	kg CO2-e per kg	Sector (t CO2-e)	kg CO2-e per kg	Sector (t CO2-e)		
Salmonids (Farmed)	Aquaculture - Cage culture		1	66,015	0.01	660	0.6	39,609	4.59	303,009	0.5	33,008	1	66,015	0.8	52,812	**8.5**	**561,128**	37%	1
Sardines	Fishing - Purse seine		0.5	21,139	0.01	423	0.3	12,683			0.5	21,139	0.3	12,683			**1.6**	**68,066**	4%	2
Other finfish	Fishing - Netting		2	124,560	0.2	12,456	0.8	49,824			0.5	31,140	1	62,280			**4.5**	**280,260**	18%	3
Prawns (wild catch)	Fishing - Trawl	27,076,852	4.2	73,649	0.2	3,528	0.8	14,112			0.5	8,820	1	17,640			**6.7**	**117,749**	8%	4
Rock Lobsters	Fishing - Pots	12,145,860	4.1	33,037			0.8	6,402	0.8	6,402	0.5	4,001	5	40,010			**11.2**	**89,851**	6%	5
Tuna (Farmed)	Cage culture		1	8,345	0.01	83	1.6	13,352	12	100,140	0.5	4,173	2	16,690	0.8	6,676	**17.9**	**149,459**	10%	6
Oysters (Farmed)	Aquaculture - Baskets	5,990,655	2.0	16,295	0.01	83	0.8	6,676			0.5	4,173	1	8,345	0.8	6,676	**5.1**	**42,248**	3%	7
Scallops	Fishing - Dredged		4	26,460	0.01	66	0.8	5,292			0.5	3,308	1	6,615			**6.3**	**41,741**	3%	8
Barramundi (Farmed)	Aquaculture - Pond/cage/ RAS		1	3,427	0.01	34	5.6	19,191	4.59	15,730	0.5	1,714	1	3,427	0.8	2,742	**13.5**	**46,265**	3%	9
Sharks/ Rays	Fishing - Netting / longline		2	10,062	0.2	1,006	0.8	4,025	1	5,031	0.5	2,516	1	5,031			**5.5**	**27,671**	2%	10
Prawns (Farmed)	Aquaculture - Pond/RAS		0.5	3,370	0.01	67	6.4	43,136	6	40,440	0.5	3,370	1	6,740	0.8	5,392	**15.2**	**102,515**	7%	11
Subtotals				**386,358**		**18,408**		**214,302**		**470,751**		**117,359**		**245,476**		**74,298**		**1,526,951**		

Notes:

* If data available via ATO data

1. **Salmonids (Farmed)** – Feed carbon intensity 4.59 kg CO_2-e per kg, based on Tassal Limited, 2021 Sustainability Report, page 38 'Total Carbon footprint of feed (CO_2-e/kg)'. Note that Tassal Ltd estimates total carbon footprint is 12kg CO_2-e/kg edible salmon meat) (page 14 of 2021 sustainability report).
2. **Sardines** – Note - Sardines are a special case, as the catch is predominantly utilised as feed for the tuna aquaculture industry in South Australia. The sardine fishery itself has a relatively low carbon footprint, it increases significantly when sardines are caught, processed, stored and then fed to farmed tuna.
3. **Other finfish** – Fuel analogue based on industry estimate for northern fisheries.
4. **Prawns (wild catch)** – High fuel use intensity. But is mitigated to some extent by no electricity and feed inputs, that create a relatively lower GHG emissions profile than for farmed prawns (source: Austral Fisheries, 2021).
5. **Rock lobsters** – Transport estimate based on long haul flight to northeast Asia.
6. **Tuna (farmed)** – Feed intensity based on *Macleod et al*. High use of sardines (see note above) creates a high GHG footprint related to feed. Power intensity based on Macleod and on existing prawn farm case studies.
7. **Oysters (farmed)** – n/a
8. **Scallops (dredged)** – Fuel intensity estimated, similar to prawn trawl.
9. **Barramundi (farmed)** – Feed carbon intensity based on salmon (source: Tassal Limited, 2021 Sustainability Report, page 38 (Best Case).
10. **Sharks/rays** – Fuel analogue based on industry estimate for northern fisheries (Austral).
11. **Prawns (Farmed)** – Feed intensity based on *Macleod et al*. Power intensity based on *Macleod et. al.* and on existing prawn farm case studies.

Table 14: Australian aquaculture & fisheries sector emissions (by scope) and segment (2019-20)

Sector Production					Scope 1					Scope 2				Scope 3				
	GVP $	Vol t	Emissions (tot)	CO_2-e/kg	Fuel	Refri-gerant	N_2O	Subtotal	% of tot	Power	Process	Subtotal	% of tot	Feed/bait	Transport	Process	Subtotal	% of tot
Fishing	**1,201**	**143,554**	**625,337**	**4.4**	288,906	17,479		306,385	49%	92,338		92,338	15%	11,433	144,259	71,094	226,786	36%
%	**46%**	**61%**	**41%**															
Sardines	$30	42,277	68,066	1.6	21,139	423	0	21,561	32%	12,683	0	12,683	19%	0	12,683	21,139	33,822	50%
Other Finfish	$372	62,280	280,260	4.5	124,560	12,456	0	137,016	49%	49,824	0	49,824	18%	0	62,280	31,140	93,420	33%
Prawns WC	$233	17,640	117,749	6.7	73,649	3,528	0	77,177	66%	14,112	0	14,112	12%	0	17,640	8,820	26,460	22%
Rock Lobsters	$521	8,002	89,851	11.2	33,037	0	0	33,037	37%	6,402	0	6,402	7%	6,402	40,010	4,173	50,584	56%
Scallops	$18	6,615	41,741	6.3	26,460	66	0	26,526	64%	5,292	0	5,292	13%	0	6,615	3,308	9,923	24%
Shark rays	$27	6,740	27,671	4.1	10,062	1,006	0	11,068	40%	4,025	0	4,025	15%	5,031	5,031	2,516	12,578	45%
Aquaculture	**1,390**	**92,872**	**901,614**	**9.7**	97,452	929	74,298	172,678	19%	121,964	46,436	168,400	19%	465,720	101,217	0	566,937	63%
%	**54%**	**39%**	**59%**															
Salmonids	$890	66,015	561,128	8.5	66,015	660	52,812	119,487	21%	39,609	33,008	72,617	13%	303,009	66,015	0	369,024	66%
Tuna	$137	8,345	149,459	17.9	8,345	83	6,676	15,104	10%	13,352	4,173	17,525	12%	100,140	16,690	0	116,830	78%
Oysters	$137	8,345	42,248	5.1	16,295	83	6,676	23,054	55%	6,676	4,173	10,849	26%	6,402	8,345	0	14,747	35%
Barra	$91	3,427	46,265	13.5	3,427	34	2,742	6,203	13%	19,191	1,714	20,905	45%	15,730	3,427	0	19,157	41%
Prawns	$135	6,740	102,515	15.2	3,370	67	5,392	8,829	9%	43,136	3,370	46,506	45%	40,440	6,740	0	47,180	46%
TOTALS	**2,591**	**236,426**	**1,526,951**	**6.5**	386,358	18,408	74,298	479,063	31%	214,302	46,436	260,738	17%	477,153	245,476	71,094	793,723	52%

* fisheries information source: *Steven, AH, Dylewski, M and Curtotti, R 2021, Australian fisheries and aquaculture statistics 2020, Fisheries Research and Development Corporation, ABARES, Canberra, August.*

iii. Issues with current Australian GHG data capture, estimates & reporting for the F&A sectors

Our review has identified several issues and opportunities for improvements to the Australian government's current procedures for GHG capture and reporting, as well as a range of general issues specific to the F&A sectors' GHG emissions reporting.

It is relevant to note that 'bottom-up' GHG information collection is highly data-intensive and may therefore be fraught with information gaps and inconsistencies compared with 'top-down' broadscale estimation techniques.

a) Government data collection and reporting

Key issues associated with the Australian government's National Accounts and NIBES data collection, estimates and reporting of GHG emissions for the F&A sectors include:

(1) Large components of emissions in Scope 2 & 3 not allocated to F&A sector

As indicated earlier, most of F&A sectors' total emissions fall within Scopes 2 and 3. However, the current NIBES and National Accounts reporting for the F&A sector is predominantly around Scope 1 emissions (direct, fuel combustion as well as some fugitive gas releases) and therefore do not provide an accurate picture of the sectors' GHG footprints.

The NIBES data for the overall sector report currently report the combined 2019 F&A sectors emissions at 713 kt CO_2-e (Aquaculture 397; Fishing 316 kt CO_2-e). Our estimates are the F&A combined GHG footprint is more in the order of 1,527,000 kt CO_2-e, or 1.5 Mt CO_2-e (Aquaculture 902,000; Fishing 625,000 kt CO_2-e).

- For **Fishing**, Scope 1 emissions are nearly 50% of this total, so for this sector, accurately capturing and reporting these emissions under the current schemes, is important.
- For **Aquaculture**, Scope 1 emissions represent just 19%, so reporting under the current measures is less relevant.

(2) NIBES data for fuel use by Aquaculture sector appears to be under-reporting

For the NIBES reporting of Scope 1 emissions from fuel use, the DISER has historically allocated fuel use in the F&A sector based on a mandatory 5 – 6% of consumption by the total Agriculture, Forestry & Fisheries (AFF) aggregation. This allocation has been based on some historical data, which may no longer be relevant. More recently, the fuel consumption allocation to the F&A sectors (and entire AFF aggregation) has been based on ABS Economic Inputs-Outputs model data and ATO Fuel Tax Credit Scheme reporting. However, these measures also appear to have issues, including:

- FTCS and fuel consumption for the Aquaculture sector appears to be under-reported, when correlated with production. It is unlikely that operators would not lodge or underclaim these tax benefits, so the lower-than-expected figures are more likely to be due to the data for the sector not being captured under the 'aquaculture' reporting codes, but under another category such as 'water transportation due to how the fuel is consumed (viz. on marine vessels)'.
- ATO and NIBES data is currently not collecting fuel use data for fishing vessels purchasing fuel outside of Australia (in accordance with international guidelines around the reporting of international bunker fuels).

(3) Scope 2 emissions not adequately considered or captured

Associated with the above issues, Scope 2 emissions (from purchased electricity) for the F&A sectors, do not appear to be adequately considered or captured under the NIBES reporting of Australian industry GHG emissions. Specifically:

- it is unclear how the F&A sectors are allocated proportions of the overall Scope 2 emissions for the AFF sector, which in 2019 were 1,483,000kt CO_2-e.
- Scope 2 emissions in the Aquaculture sector may also be under reported and underestimated in the entire NIBES inventory. Electricity consumption in land-based pond aquaculture is significant (we estimate it may represent up to 45% of total emissions for the prawn and barramundi farming industries).
- Purchased electricity use for the large cage culture industries is associated with processing and hatchery operations, and emissions therefore appear not to be captured under Aquaculture and may be reported under other classifications such as 'food processing'. For example, Tassal Group, the largest aquaculture producer in Australia reports Scope 2 emissions (2021) as nearly 40% of its total Scope 1 and 2 emissions.
- Calculating Scope 2 (and Scope 1) emissions intensities for small aquaculture industries such as barramundi and lobsters are more difficult because of production data anonymisation for confidentiality reasons.

(4) Fugitive emissions may be inappropriately and inadequately reported

Under the National Accounts and NIBES reporting, the methodologies used to estimate certain non-combustion emissions - specifically nitrous oxides (N_2O) - categorised (under Scope 1) may not be appropriate.

(a) <u>Wetlands related emissions</u>

- Currently in the National Accounts there is reporting of emissions for the Aquaculture sector, calculated under methods for Land Use, Land Use Change & Forestry (LULUCF) and specifically for Wetlands associated emissions. The methodology, described as "Wetlands remaining Wetlands", is nominally a calculation of N_2O emissions from the production of finfish and crustaceans in aquaculture systems located in coastal wetland habitats – deriving from two aspects: 1) clearing of coastal wetlands (and their drying); and 2) direct emissions from ponds containing fish and crustaceans which includes N_2O but also CH_4 and CO_2.
- The general methods under the LULUCF and "Wetlands remaining Wetlands" components are spatial, associated with the calculation of areal changes of vegetation removed or changes to the land systems which impact on them acting as emissions sources or sinks.
- Currently, the methodology used by DISER:
  - does not use a 'spatial 'approach and therefore does not calculate emissions associated with displaced wetlands or other areal coastal land-use changes.
  - uses a 'biomass' approach but which may be inaccurately applied in volume and only calculates N_2O emissions. Currently, the method applies aquaculture 'groups of interest…that are mostly cultured in coastal wetland-based facilities… and therefore…fish production for salmonids, tuna, barramundi and prawns to calculate an annual N_2O emissions for <u>all</u> aquaculture in Australia. The method appears to be utilising a coastal wetlands method and applying a component (N_2O emissions) to all aquaculture, which is predominated by caged culture production in temperate coastal waters.
- This method needs further assessment and refinement. Moreover, there are more significant areas of aquaculture emissions which could be determined to provide a better assessment of the footprint

of the industry. Nonetheless, in the National accounts, estimates of emissions associated with wetland methane emissions, seagrass losses from dredging and enteric emissions for animals such as ostrich flocks are currently estimated, so comparatively, it should be possible to apply similar methodological principles to the aquaculture industry, to gain more accurate and meaningful data. For land-based pond aquaculture (predominantly in Queensland) the estimation of emissions would nominally focus on:

- area of new ponds created – which have removed coastal wetlands (mangroves, coastal marshes, etc.) removing carbon sinks.
- area of existing ponds – in which coastal wetlands are not able to regenerate, and which produce GHG emissions because of:
    - decomposition of organic (e.g. excreted N wastes, uneaten feed) and inorganic materials (fertilisers) in the ponds which release nitrous oxides (as NO_2), but also methane (CH_4) and other volatiles, and
- gases produced by animals in the ponds (therefore a function of the entire biomass) predominantly, carbon dioxide resulting from the respiration of the biomass, but also NO_2, CH_4 and other volatiles.

(b) Refrigerant gas losses

In addition, refrigerant gases used in the F&A sectors which are lost from vessel or 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 Fishing sector. They appear to be much less significant for the Aquaculture sector.

(5) Fuel Tax Credit Scheme issues

The Fuel Tax Credit Scheme could be better utilised to measure fuel consumption and GHG emissions. There are several improvements that could be made to FTCS reporting for the F&A sectors, which would be beneficial for government and industry in both measuring fuel use and efficiency and GHG reporting.

Key improvements would include:

- the FRDC representing the F&A sectors to work with DISER and the ATO to request that the ATO meta-data retain the full BIC descriptions for businesses submitting FTCS claims, to enable more comprehensive and accurate reporting of diesel use in the Australian seafood sectors.
- The Aquaculture sector – particularly those with substantial cage culture operations – to assess whether FTCS claims being captured under aquaculture related BICS particularly for its marine vessels, or whether they are being reported under other industry classifications such as marine transportation. This will also enable more comprehensive and accurate reporting of diesel use in the Australian aquaculture sectors, which currently appears to be under reporting on fuel use.

b) Other reporting improvements

(1) Capturing Scope 2 emissions (Aquaculture) – purchased power

- Scope 2 emissions from electricity purchased may be better calculated by enterprises and aggregated/reported by industry associations as a supplement to current methods. Power purchases are significant factors in the costs of onshore aquaculture production for prawns, barramundi, and abalone. Industry studies on power use are a decade old or more (Millar *et al*) but rule of thumb for prawns would indicate pumping, circulation, and aeration requirements in the order of 6 to 8 kWh of energy per kilogram of production. However sectoral power use data for prawn farm aquaculture or barramundi farm aquaculture, for example, are not publicly available. It may be more pragmatic to expect that individual businesses, rather than industry associations, may be motivated to determine their own energy usage from itemised power bills, and hence derive an estimate of their greenhouse gas emissions.

- Emissions from Australian power production are reported to the Clean Energy Regulator at a generator level and can thus be aggregated to a State or grid-connected network level. Emissions factors for electricity purchased from commercial grid participants are available in the National Greenhouse Accounts Factors, published as part of the Australian National Greenhouse Accounts reporting. This should enable electricity purchasers to estimate the emissions factor of that electricity (or ask their power provider for an estimate) and so estimate Scope 2 emissions relating to their business.
- The GHG Calculator Tools provided as Program 2 of this study provide some mechanisms for enterprises to calculate their own emissions, including Scope 2 emissions. The text box below is an example of estimating emissions profile from electricity use for farmed prawns.

Expected industry footprint for farmed Prawns

The estimated emissions factor associated with grid-connected energy in Queensland is 0.82 kg CO_2e per kWh (second highest overall state-level EF to Victoria: black coal, with a typical EF of 0.89, is used to generate 85% of Queensland's reported electricity production). Thus, using the indicative energy figures above, Scope 2 emissions related to electricity purchases equate to 4.9 – 6.5 kg CO_2-e per kg of production. This figure is consistent with South and East Asian on-farm energy use intensity figures for prawn production shown in Macleod et al[23] To this figure, an allowance should be added for diesel fuel (industry figures not available but expect 0.25-0.12L diesel/kg prawns) and a further (estimated 6 kg CO_2-e per kg) allowance for Scope 3 emissions associated with feed. Interestingly the carbon footprint from electricity alone for Australian farmed prawns is significantly higher than the carbon footprint attributed to diesel use in Australian prawn fishing.

Greenhouse gas intensity data related to electricity generation is available at generator level, from the Clean Energy Regulator.

c) Capturing Scope 3 emissions

Transportation (third party) represents a significant source of Scope 3 emissions within the F&A sectors. For the fishing sector, processing is also a significant component but within aquaculture more processing is in-house and is captured as Scope 2 emissions. For Fishing, the use of bait also represents a significant but often overlooked emission component. For aquaculture, feed inputs constitute the largest Scope 3 emissions component.

(1) Feed input emissions – a significant GHG contributor

- Feed inputs are the most significant GHG contributor to the carbon footprint of the Aquaculture sector. Contemporary estimates in the available scientific literature show that **formulated feeds may represent over 50% of a farming operation's overall greenhouse gas emissions footprint**. Moreover, data for feed, which is a Scope 3 emission, has not been accounted for the in Australian Greenhouse National Accounts or NGERS emissions profiles of aquaculture producers, and is a significant data issue for the aquaculture industry and businesses trying to evaluate their carbon footprint. The Australian National Accounts aquaculture industry emissions calculations or tools, without a Scope 3 emissions assessment including feed, are inherently compromised and are probably grossly under-reporting.
- Feed companies' data has only recently been disclosed in aquaculture producer's carbon footprint calculations and information available to customers or potential customers. This was due to:
    - complexities in the quantification of the embodied emissions in each of the many components of feed and stages of feed manufacture, and

[23] MacLeod, M.J., Hasan, M.R., Robb, D.H.F. et al. Quantifying greenhouse gas emissions from global aquaculture. Sci Rep 10, 11679 (2020). https://doi.org/10.1038/s41598-020-68231-8

- the government GHG emissions reporting focus only on direct (Scope 1) and electricity (Scope 2) emissions and Scope 3 not being required to be reported

- As indicated, the evaluation of embodied GHG emissions in aquaculture feeds is complex and contain numerous technical components and considerations. **Figure 9** (from Macleod *et al*) illustrates this point.

Name	Description
Feed: fertilizer production	Emissions arising from the production of synthetic fertilizers applied to crops
Feed: crop N_2O	Direct and indirect nitrous oxide from the application of N (synthetic and organic) to crops and crop residue management
Feed: crop energy use	CO_2 from energy use in field operations, feed transport and processing
Feed: crop LUC	CO_2 from land use change arising from soybean cultivation
Feed: rice CH_4	Methane arising from flooded rice cultivation
Feed: fishmeal	CO_2 from energy use in the production of fishmeal
Feed: other materials	Emissions from the production of a small number of "other" feeds (including animal by-products, lime and synthetic amino acids)
Feed: blending and transport	CO_2 from energy use in the production and distribution of compound feed
Pond fertilizer production	Emissions arising from the production of synthetic fertilizers applied to increase aquatic primary productivity
On-farm energy use	Emissions arising from the use of electricity and fuels on fish farm
Aquatic N_2O	N_2O from the microbial transformation of nitrogenous materials (fertilizers, excreted N and uneaten feed) in the fish farm water body

Figure 9: Component considerations for GHG emissions footprint calculations for aquaculture feeds (from Macleod, et al.)

- A growing number of Life Cycle Assessment (LCA) analyses have been performed to determine the GHG emissions footprint of aquaculture feed. Nonetheless, the information published by feed companies has typically been quite generic and there are no definitive publicly available databases regarding the footprints of feed products on a company-by-company basis. Currently, most of the information provided by feed companies tends to be related to the "Feed: blending and transport" component – which typically represents a very small proportion (3% to 5%) of a compounded feed's overall carbon footprint. This means aquaculture farmers have not been readily able to evaluate the relative carbon footprint of alternative feeds from competing providers and have been unable to estimate the emissions from that feed on their own farming operations.

- However, feed manufacturers, in particular the larger companies such as Skretting and BioMar, are taking significant steps in advanced carbon accounting methodologies for the raw materials used in their feeds. Several feed companies collect primary data from suppliers and work directly with their suppliers to improve footprints. In addition, all the major feed companies report to the Science Based Targets initiative (SBTi) where they disclose scope 1, 2 and 3 emissions on a yearly basis.[24] Some also have commenced disclosing per kilogram emissions (including scope 1, 2 and 3) in annual reports, sustainability reports and directly to customers seeking this information. It is quickly becoming more standard practice to do this and importantly, it will soon be part of the Aquaculture Stewardship Council (ASC) certification.[25]

- An accurate analysis of the carbon footprint of aquaculture operations requires adequate data on the GHG emissions profiles of all feed inputs. Industry will need to continue to work together to enable greater determination and disclosure of GHG emissions associated with feed for better reporting directly and through the product supply chain, to consumers. Standardised carbon footprint metrics for feeds may be a valuable tool for farmers to assess the carbon profiles of their products and overall, to compare seafood products against other competitive farmed protein offerings.

[24] See: SBTi website at: https://sciencebasedtargets.org/
[25] See: https://www.asc-aqua.org/what-we-do/our-standards/feed-standard/

> ‘As a source of protein, aquaculture has one of the lowest carbon footprints, but it is important that the industry monitors and works to reduce its footprint along the entire supply chain. ASC certified feed mills will have to record and report their energy use and greenhouse gas emissions: and work to improve energy efficiency, use of renewables, and water usage.’
>
> **Chris Nines, CEO of the Aquaculture Stewardship Council**

d) Scope 3 Emissions (Fishing) - Purchased Bait

As highlighted in earlier sections, purchased bait is an often-missed Scope 3 emissions input in the Fishing sector. It is an issue particularly for the Rock Lobster and Shark/ray fisheries and contact with the Western Rock Lobster Association confirmed that it and its members were becoming aware of its significance and the need to understand the carbon dynamics better.[26]

Whilst some GHG calculators include a ‘bait’ input component, there will probably be a greater obligation for bait producers to undertake their own carbon calculations to capture this and to be able to report it to their customers (fishers), which in-turn they can incorporate the information into their own supply chain emissions calculations.

[26] Daniel Fels, *pers comm*., Western Rock Lobster Association, Perth, 2 August 2021.

3. Energy & GHG emissions self-assessment tools (Program 2)

a) Background

The key objective of Program 2 was to develop tools for energy & GHG emissions self-assessment, able to be readily utilised by the Australian F&A sectors.

b) Methodology

This program developed three Microsoft Excel-based calculation and reporting tools for distribution by FRDC to the F&A sectors to enable enterprises to readily self-assess and calculate their total energy use and GHG emissions.

Companies may choose to report their data to either their industry association or fisheries management body, FRDC or even the National Greenhouse and Energy Regulator (which has a voluntary reporting scheme). Larger F&A companies with considerable energy use already report under the NGER scheme. In addition, ASC and MSC certification programs also assess companies' management of GHG emissions.

For most fisheries, Scope 1 emissions from direct fuel use will be the largest single contributor to the overall inventory and will be relatively easy to document. As indicated in Program 1, fishing companies will prepare Fuel Tax Credit Scheme claims based on diesel fuel consumption which can also be readily used for emissions calculations. Similarly for most aquaculture companies, Scope 1 emissions will be easily derived, whilst Scope 2 emissions derived from purchased electricity consumption – particularly significant for land-based producers – will also be relatively easy to ascertain.

However, it is Scope 3 – third-party energy use and emissions – derived from supply chain inputs which for most businesses will be the most time-consuming and potentially difficult components to accurately ascertain. In order for F&A businesses to build an accurate profile of the emissions of their production life cycle, third-parties will need to calculate and provide their emissions data to F&A businesses. Typically for most industries, Scope 3 emissions are a minor contribution to the overall accounts for energy and GHG emissions. However, for food production Scope 3 is much more significant and for Aquaculture (and to a lesser extent for Fishing), there may be 20 – 50 individual contributions making up the profile for a seafood product supply chain.

c) Key findings

Key findings from Program 2 Develop a self-assessment tool for the Australian Fishing and Aquaculture sectors - to calculate energy efficiency and GHG emissions are discussed below.

i. Review of existing energy & GHG tools

A first step in the development of tools was a review of existing tools. Our review included overseas fisheries GHG calculators as well as GHG tools utilised in other relevant sectors, such as transport, food production and processing.

Three GHG tools included in our initial review of other overseas fisheries GHG calculators, and several tools utilised in other sectors that are relevant to Fishing and Aquaculture are described below.

a) *The Seafish 'Seafood CO_2 Emissions Profiling Tool'*

The Seafish Industry Authority (known simply as Seafish) is a UK statutory body established under the *Fisheries Act 1981* as the peak industry body for the seafood industries in Great Britain.

The Seafish *Seafood CO_2 Emissions Profiling Tool* was developed in partnership with Dalhousie University in Canada and SINTEF (a Norwegian independent research organisation). The purpose of the Seafish tool is to allow users to explore the carbon implications of sourcing and supplying seafood, with the aim of providing a better understanding of the major contributors to energy use and GHG emissions of seafood products.

The tool also provides insight into the influence that some aspects of the seafood production chain have on carbon emissions. Major potential drivers of emissions that the tool addresses include direct fuel inputs to fishing, the form and scale of transport used, and the amount of time products are held in cold storage. This tool incorporates yield rates and the degree to which processing co-products (wastes) are utilized, and users may alter all these variables.

This is a comprehensive, web-based tool for fisheries that includes transport and pre/post processing refrigeration. However, aspects of the seafood life cycle including emissions associated with bait, and seafood product packaging are not currently covered within the model. In addition, the Seafish tool is not consistent with Scope 1, 2, 3 methodologies used in Australia.

A copy of the tool is available at: http://www.seafish.org/ghgemissionsprofiler/

b) *UK Greenhouse Gas Protocol - Mobile Combustion GHG Emissions Calculation Tool Version 2.6*

The UK Greenhouse Gas Protocol - Mobile Combustion GHG Emissions Calculation Tool was developed by the UK government, specifically for the transport sector and calculates CO_2, CH_4 and N_2O emissions for an enterprise from:

- Vehicles that are owned/controlled by the enterprise, including freight lorries
- Public transport by road, rail, air, and water, and
- Mobile machinery, such as agricultural and construction equipment.

The tool uses default emission factors, which vary by country. Currently, separate sets of emission factors are available for the UK and US. For other countries, if more specific emission factors are not available, companies can select 'Other' category and input local factor data, or default global values. Accuracy of the calculations will therefore depend on the accuracy of the local data utilised. On the settings tab, users can supply custom emission factors or adjust the default global warming potentials (GWPs).

The GHG Protocol tool for mobile combustion. Version 2.6. is available at: https://ghgprotocol.org/calculation-tools .

c) *Fishing Vessel Energy Analysis Tool (FVEAT)*

The *Fishing Vessel Energy Analysis Tool* (FVEAT) was developed by the Alaska Fisheries Development Foundation (AFDF) a key research agency[27] and developed for the commercial fishing industry in Alaska, USA. The tool was developed because of the rising cost of fuel and its significant impact on commercial fishing businesses in Alaska and the absence of an off the shelf EU and GHG emissions calculator applicable for wild catch fisheries and aquaculture.

[27] See: https://www.afdf.org accessed: 27 August 2021.

To provide vessel owners with information to make decisions about how to improve fuel efficiency on their vessel, the Alaska Fisheries Development Foundation (AFDF) partnered with the Alaska Longline Fishermen's Association (ALFA), Alaska SeaGrant, Nunatak Energetics, and Navis Energy Management Solutions to conduct energy audits and collect data from more than 40 Alaskan fishing vessels between 2012 and 2017. This work resulted in the Fishing Vessel Energy Analysis Tool (FVEAT). The FVEAT combines user data with measurements from Alaskan vessels participating in commercial troll, longline, seine, gillnet, and pot fisheries to generate an energy use profile specific to the user's vessel.

It is a web application based on the knowledge gathered from the initial database in conjunction with personalised information about the user's fishing habits and hardware. The system produces a personalized vessel report with recommendations for reducing energy consumption. Fishers can return to earlier pages and enter altered parameters to determine which changes are economically worthwhile. Links are provided on the AFDF website to additional information on improving fuel efficiency.

A copy of FVEAT is available at: www.afdf.org/projects/current-projects/fishing-vessel-energy-efficiency/ .

ii. Australian F&A self-assessment tool development

a) Tool development background

There are a range of energy efficiency programs that have been developed internationally in the fisheries sectors, primarily targeting fuel efficiency in operations of diesel engines on fishing vessels, primarily to reduce operating costs and in some cases to reduce emissions. However, there is currently, no off the shelf EU and GHG emissions calculator broadly applicable for both wild catch fisheries and aquaculture, due primarily to the differences in their operations. However, there are several Australian produced energy use and GHG calculator tools produced for a variety of industries (including other primary production and food production) which have some applicability to the F&A sectors.

There are only a couple of energy use calculator tools (produced overseas) specifically developed for the fisheries sector. Several have good potential for adaption to the Australian fisheries sectors, however there are no off the shelf EU and GHG calculators specifically for aquaculture.

To satisfy the wide variety of fishing and aquaculture operations, we sought to develop a minimum of three separate tools as listed below. It is estimated that these three models will potentially cover 80% of all F&A operations in Australia.

b) F&A GHG models developed

The three models cover:

- **Fisheries** – for large fleets, trawlers, purse seine vessel-based fisheries and for small vessel-based fisheries utilising traps, pots, entanglement nets.
- **Offshore Aquaculture** – offshore cage grow-out operations, with onshore processing
- **Onshore Aquaculture** – land-based ponds and processing.

Other models for future development may include RAS-style operations, and oyster, mussel, and seaweed aquaculture.

Businesses can relatively readily acquire data for energy use via electricity billing or liquid fuels purchases. However, other data regarding refrigerant leakage (relevant to wild catch fisheries) and emissions relating to formulated feed use (relevant to aquaculture) may be less easy to access, and potentially represent significant information gaps which distort emissions reporting.

As part of the project, we have reviewed the use of reasonable values for refrigerant and feed emissions factors as they relate to greenhouse gas emissions for F&A businesses to be incorporated into tools for the F&A sectors.

(1) Model framework and metrics

Prime goals for the tool development were:

- simplify the process for a fisher, or fish farmer, to estimate the GHG emissions profile (often called the carbon footprint) of their business, and
- make the tools relatively intuitive and simple for a business to use and generate reports.

The tools developed are Excel-based and can be readily distributed and used by fishers and SMEs in the F&A sectors to self-assess and calculate GHG emissions. These tools are notably simpler and more focussed to a fishing business level than the existing overseas tools reviewed in. Companies may choose to report their data to either their industry association or fisheries management body, FRDC or even the National Greenhouse and Energy Regulator (which has a voluntary reporting scheme).

The tools calculate GHG emissions for a business based on best-available emissions factors associated with each business metric.

What information do I need to use the tool?

This is the key information that a business will need to have at hand, to get best value from the tool, for a recent season or year:

Fisheries businesses	Aquaculture businesses
Quantity of fish caught	Quantity of fish harvested
Species of fish caught	Species of fish grown
Quantity and type of bait used in the business	Quantity and type of feed used in the business
Both Fisheries and Aquaculture businesses	
Volume and type of fuel used directly in the business	
Volume and type of refrigerant used directly in the business	
Amount of electricity purchased for use in the business	
Transport and Processing	
Information regarding the carbon footprint of processing and transporting product may be more difficult for businesses to obtain. Here the tools ask for less detailed information	
Processing types, and yields, associated with the business's product	
Mode of transport, and transport distances, associated with the business's product before and after processing to the point of final sale or storage	

Figure 10: Self-assessment tool metrics

Emissions factors are well understood for many factors of production in both fishing and aquaculture businesses. The best known and understood include the greenhouse gas emissions factors applicable to:

- liquid fuel combustion for various fuel types
- refrigerant release for most refrigerant types
- electricity purchases from grids in all states in Australia, and
- sea, rail, and the key modes of road and air transport.

The **electric power requirements of different types of seafood processing** are also reasonably well known and internationally benchmarked. In addition, most of the emissions factors for many of the factors of production in both Fisheries and Aquaculture are well understood. However, there is still some key information that may not be available to fisheries and aquaculture operators, because it is difficult to obtain, or has some commercial confidentiality.

Key information unknowns or data 'unavailability' may include:

- **Embodied greenhouse gas emissions in aquaculture feeds**. Fresh or frozen whole fish is in theory a simple input feed. However, to determine its carbon footprint as a feed for other fish, requires a good understanding of the source fishery (for example: sardines) as well as the other supply chain steps involved in delivering the product to the farm and to the fish. Formulated feeds which contain a multitude of ingredients, many with long supply chains, are much more complex and complicated. A fish farming business cannot be expected to perform this complex evaluation and should request their feed supplier provide the carbon footprint for each feed type purchased. For aquaculture operators whose feed suppliers are unable to provide their feed's carbon footprint, the self-assessment tools use current "best-guess" estimates for formulated feeds and will provide an estimate of the GHG emissions embodied in the feed in the absence of accurate emissions data from the feed supplier . See section **Feed input emissions – a significant** for a discussion on the carbon footprint of formulated feed, and the importance of feed industry disclosure.
- **Embodied greenhouse gas emissions in the bait used by fishing businesses**. The emissions associated with producing the bait (whether marine or terrestrial) combined with the emissions associated with transporting the bait from its production point to dockside, may be difficult for a fishing business to determine. In many instances, a fishing business may purchase bait from a wholesaler – who themselves may have no idea of, or inclination to determine, the GHG footprint of the bait.
- **Embodied greenhouse gas emissions related to fugitive refrigerant emissions from third party processing**. Because processing may be performed by third party operations, it may be difficult to obtain information regarding operational metrics such as fugitive refrigerant gas emissions.
- **Emissions associated with transport to market.** This uncertainty is inherent in transport emissions relating to products that may be on-sold to traders, held in storage for long periods, and/or transported to unknown or multiple destinations. Products where an overwhelming proportion of production is sent in a single form to a single market, are the exception rather than the norm.

iii. GHG tool – input screens & outputs

Key input and output screens for the GHG calculator tools developed are presented in the graphics below.

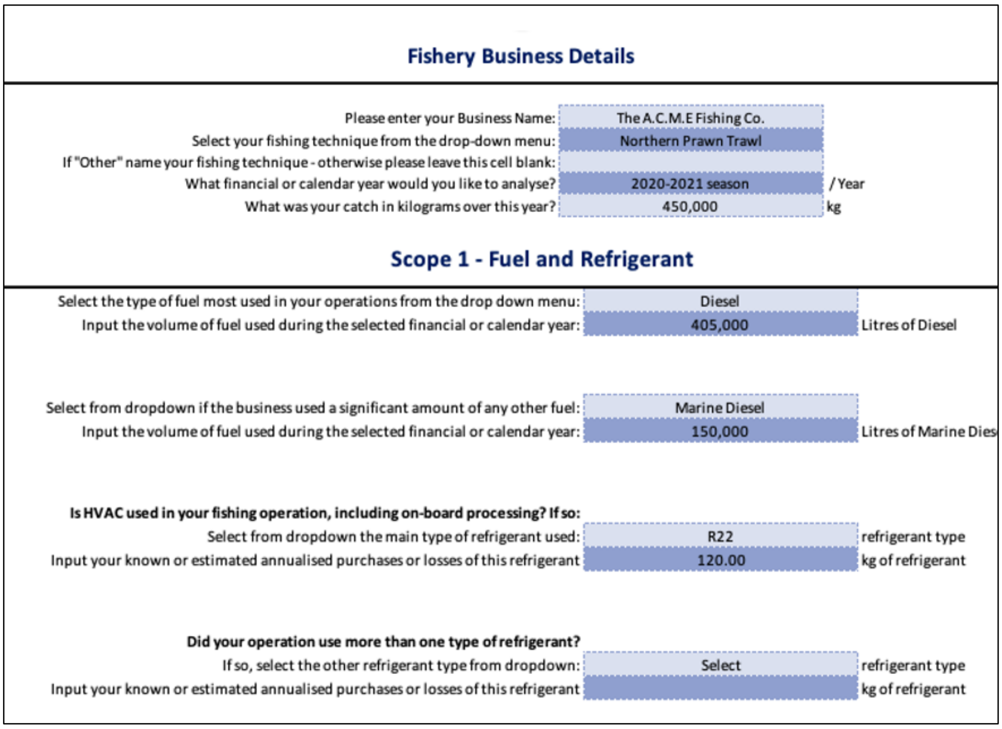

Figure 11: Sample input page with values entered for a fictional fishing business

Outputs are presented in a simple chart that demonstrates the size and relative importance of the business's key greenhouse gas emission categories.

Figure 12 provides an output screenshot of the Fisheries Self-assessment GHG footprint tool (using a fictional trap or pot fishery business).

Figure 13 provides a screenshot of output the Self-assessment GHG footprint tool, for a fictional trawl fishery business.

Figure 14 provides a screenshot of the Self-assessment GHG footprint tool, for a fictional ponded aquaculture business and **Figure 15** for a sea cage aquaculture business.

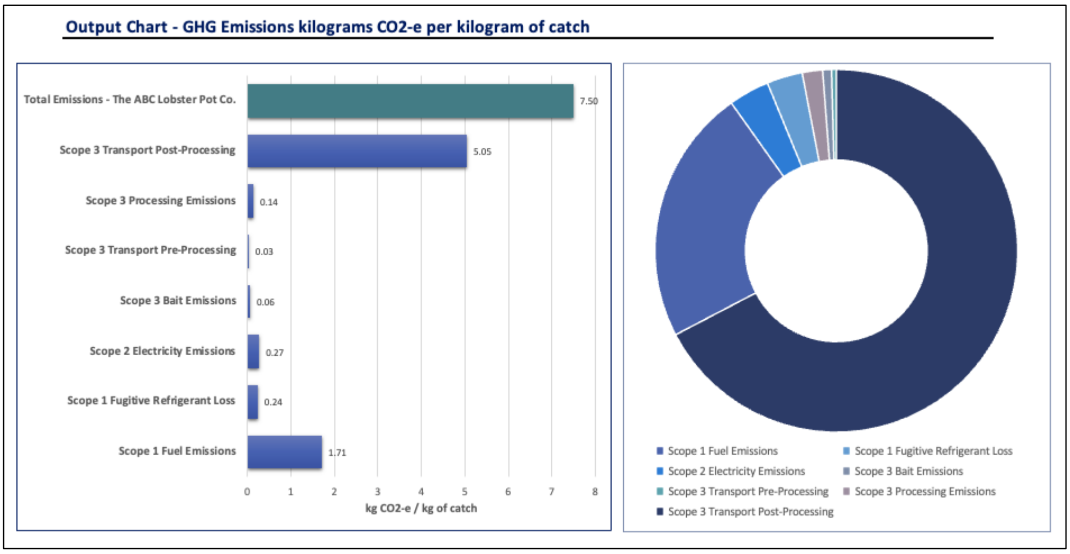

Figure 12: Sample output of the Self-assessment GHG footprint tool, for a fictional trap or pot fishery business

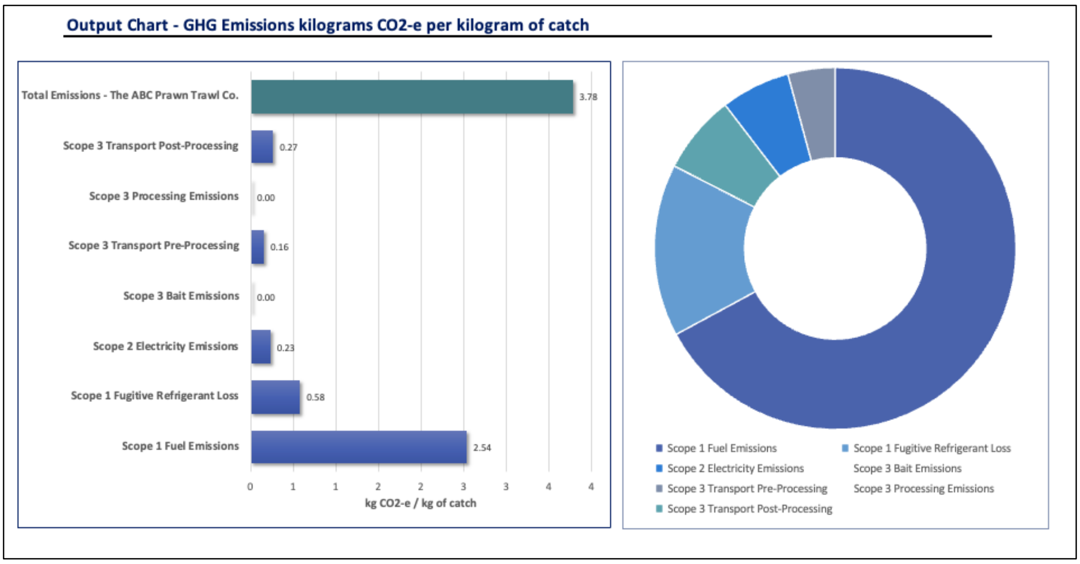

Figure 13: Sample output of the Self-assessment GHG footprint tool, for a fictional trawl fishery business

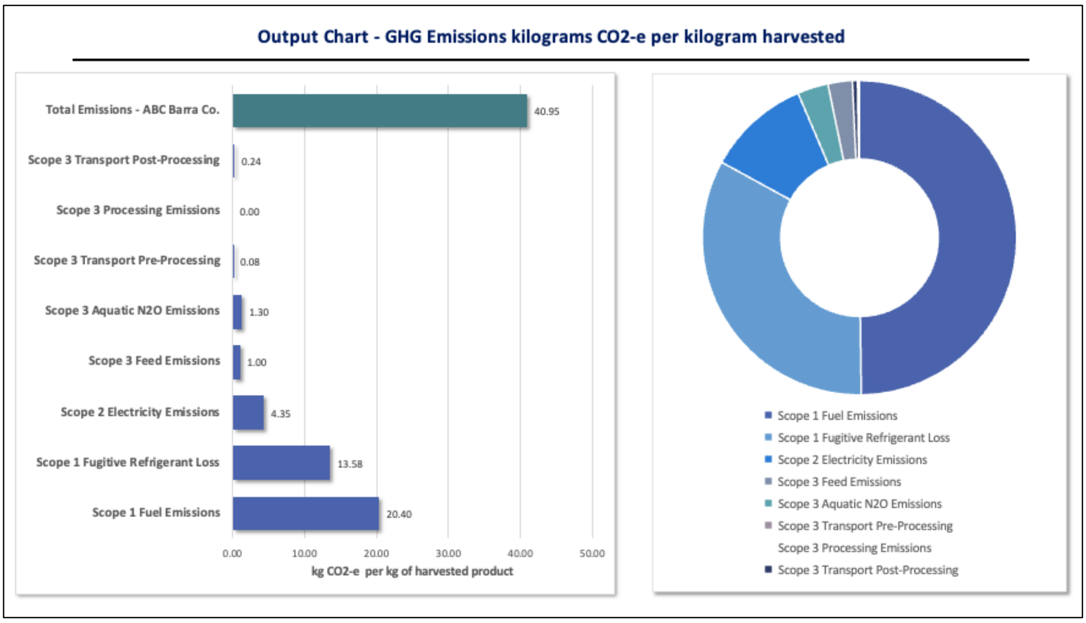

Figure 14: Sample output of the Self-assessment GHG footprint tool, for a fictional ponded aquaculture business

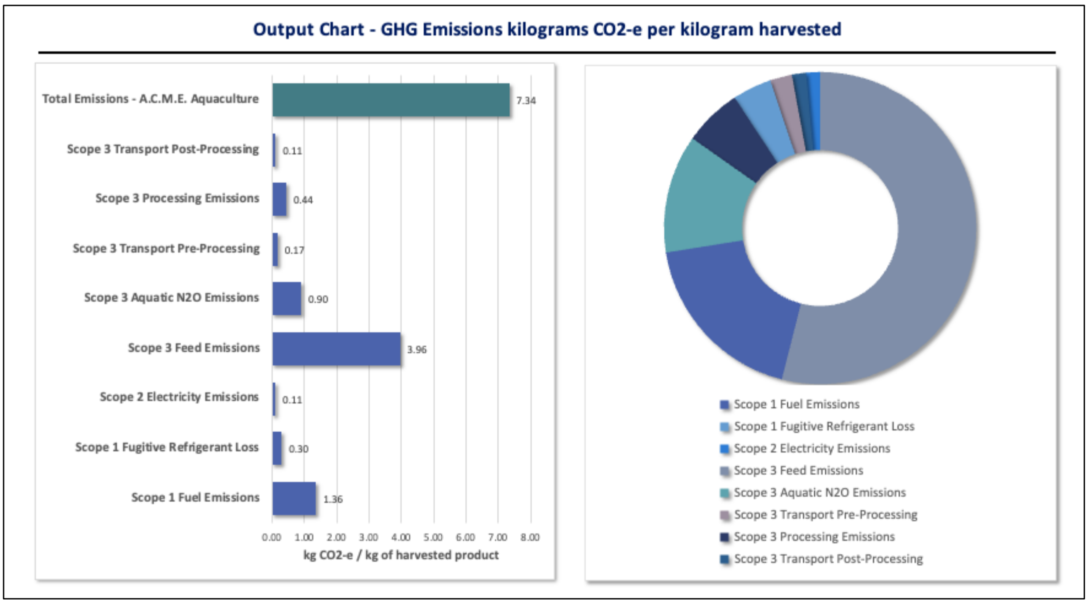

Figure 15: Sample output of the Self-assessment GHG footprint tool, for a fictional sea cage aquaculture business using tools for forward planning

Because each of the elements in the tools can be ‘flexed’, they can be used to investigate sensitivities to changes or alternative business operating procedures and their resulting GHG outcomes, which can be used for business planning or specifically GHG emissions reductions plans.

Examples of how the models can be ‘flexed’ include:

- Fishing business – the effects of changes in fishing practices – boat, gear, catch effort
- Aquaculture business – the effects of changes in electricity consumption, tariffs, or supplier
- Fisheries or aquaculture business – the effects of changes in transport modality at any point in the supply chain.

4. Emissions reduction opportunities in the fisheries & aquaculture sectors: a toolbox (Program 3)

The key objective of Program 3 was to provide a toolbox – several different types of examples and approaches – able to be utilised by Australian F&A companies:

- as guides and incentives to reduce their energy use and GHG emissions/footprint, and
- to provide information on how to present and promote these achievements with customers.

a) Background

Globally, the top 150 seafood companies have combined total revenue exceeding US$120 billion. The top five, which include Japanese giants Maruha Nichiro, Nippon Suisan Kaisha (Nissui), as well as Norwegian salmon farmer Mowi, fish feed producer Skretting and major tuna, shrimp, smoked salmon, and canned processor Thai Union -- account for nearly $30 billion. Consolidation has also blurred the lines between aquaculture, fisheries, processing, and feed companies, with giants such as Norway's Austevoll Seafood diversifying across the full value chain.

The market cap for the top 5 publicly listed seafood firms now exceeds $44 billion. As sales and earnings have risen, so has investor interest, both in the private equity and institutional sector. The growth is by no means over. The increasing popularity of seafood products and consolidation of the supply sector into larger, more sophisticated companies is expected to drive industry growth even higher in the coming decade.

This F&A activity is driving incredible scrutiny on environmental, social and governance (ESG) issues in investments in the seafood sector, as seen in Australia recently with the takeover of Huon Aquaculture by Brazilian beef production giant JBS. Increased financial market attention to the F&A sector will drive greater disclosure and with his will come greater stakeholder (shareholders and external party) expectations around sustainability, GHG reduction and action to seek to manage the effects of climate change.

In Australia, the F&A sector – largely comprised of SMEs and family businesses – currently has a low level of energy use accounting and GHG reporting. It also has a relatively low representation in public and consumer disclosure on carbon footprints, despite the value of the seafood produced and volumes supplied to many consumers. In addition, the data collected and presented within Australian national reporting measures is not complete and does not provide an accurate picture of the F&A sectors' GHG emissions and profile. Whilst potentially 'flying under the radar', consumers are increasingly demanding carbon footprint data on their food purchases and the seafood sector will need to be constantly and consistently providing information about its products to compete for market share in the food protein sector. But many industries within the F&A sector will need to firstly get informed, gather data, develop strategies, and assess approaches, before grasping these challenges.

Therefore, we believe as a first step for many operators, providing self-assessment tools, combined with guidance on public disclosure and 'marketing' of GHG performance provides:

- a good cost-benefit approach
- can lead to high levels of industry uptake and
- can help develop greater capability and capacity for the F&A sectors to start to achieve reductions in energy costs and demonstrate responsible management of its GHG emissions.

b) Methodology

In addition to the GHG calculator tools we have presented several 'case studies' to highlight the use of GHG programs, tools and outcomes from the F&A sectors or other industries.

General approaches include implementation of fuel efficiency measures, fuel swapping, fuel-saving operational programs, alternative electricity (low GHG) generation sources as well 'cooperative' programs with suppliers and downstream partners to reduce energy use and emissions in the overall product supply chains.

We have also produced specific case studies for F&A companies to potentially adapt and utilise in their own stakeholder (particularly customer) communications and marketing tools. These may also support the opportunities for 'GHG friendly' certification/acknowledgement for seafood products or presenting GHG accounts as key elements of ASC certifications.

c) Marketing & carbon neutrality

Most businesses rely on marketing to maintain and increase sales and profitability and more savvy that promotes or differentiates their business, brands or products or touches consumer sentiments or needs will generally sell more product.

So, what is the role of marketing decisions in addressing climate change when juggling the pressures of consumers and governments, through tools such as carbon footprinting and pricing?

The following are a series of points developed from theoretical marketing strategy applied to the notion of selling a lower carbon footprint enterprise or product.

1. **Climate concerns of consumers and governments provide incentives to reduce the carbon footprint of products and organizations.**

The potential impact of climate change raises concerns with consumers and governments throughout the world. Dealing with these climate concerns may become a key to the survival of businesses in the marketplace, and ultimately the survival of the planet.

Calculating carbon footprints has become standard procedure, and they are now routinely reported by organizations according to international accounting standards to allow consumers to make better purchase decisions. Marketing can play an important role in this, through developing products and services that have a low carbon footprint—the climate impact measured in carbon dioxide equivalent (CO_2-e) emissions.

2. **Lower carbon footprints may increase costs but may also increase demand**

The starting point in any discussion regarding marketing an enterprise's carbon footprint is the general observation that reducing the footprint of a product affects costs, but also demand. While greener products are generally more costly to produce, there is ample evidence to demonstrate that consumers tend to purchase more at a given price when products have a lower carbon footprint.

Enterprises considering the climate concerns of its product consumers can choose the (size of its) carbon footprint and the price of the product (or service). Therefore, if lowering the carbon footprint (e.g. by using less energy) reduces unit cost, then it is optimal to increase efficiency by eliminating waste. Such green cost cutting is even more attractive to the enterprise if lowering the carbon footprint not only reduces cost, but also increases demand due to better environmental performance of the product.

On the other hand, if lowering the carbon footprint increases unit cost (e.g. by buying offsets), there may be a trade-off between the cost effect and the demand effect. Clearly, without a positive demand effect, lowering the carbon footprint only raises costs and is therefore sub-optimal. However, when consumers are sufficiently responsive to the better environmental performance of the product, it may be optimal for an enterprise to engage in cost-increasing sustainability and offer a product with a lower carbon footprint.

3. Stronger climate concerns may lead to greener product design…

Stronger climate concerns increase the demand effect and the incentive to engage in cost-increasing sustainability. At the same time, the cost effect motivates an enterprise to increase prices, which results in lower demand. Taken together, these demand and supply-side effects jointly determine the relative profitability of adjusting the carbon footprint and price.

In a market where the demand effect outweighs the cost effect, stronger climate concerns provide an incentive for a firm to design a greener product with a lower carbon footprint. In general, though, stronger climate concerns do not necessarily motivate enterprises to offer a greener product in the marketplace because the cost effect may outweigh the demand effect.

4. …but may increase the organizational carbon footprint

The optimal marketing strategy determines the overall climate impact of a firm—the organizational carbon footprint. This aggregate environmental impact is the result of multiplying the product carbon footprint by overall sales.

Surprisingly, research indicates that offering a greener product in response to stronger climate concerns does not necessarily reduces a firm's overall level of carbon emissions. This occurs because the demand effect of lowering the carbon footprint may translate into higher sales and thus a greater organizational footprint—a situation where a firm that offers a greener product becomes a victim of its own success.

Designing greener products can therefore conflict with the objective of meeting climate targets mandated by law. This points to a potential tension between the objectives of marketers, operations managers and those tasked with reducing the organization's climate impact.

5. The role of carbon regulation: caps and taxes

Governments are increasingly putting a price on carbon emissions to make firms pay for their impact on the climate—costs that are otherwise born by society. How do cap-and-trade systems and carbon taxes affect the optimal marketing strategy?

A cap-and-trade system allows an enterprise to choose between two options: adjust its marketing strategy to meet the limit set by the regulator at the organizational level or stick to the current marketing strategy and decisions about the carbon footprint and price, and purchase carbon allowances (also termed 'offsets' or 'credits') in an emissions market.

While a binding carbon cap clearly reduces the organizational carbon footprint and an enterprise's profit, the impact on the carbon footprint at the product level is ambiguous. This results from the fact that an enterprise has an incentive to increase the carbon footprint and thereby purposely reduce sales to meet the carbon target (de-marketing). Therefore, a carbon regulation at the organizational level may have the unintended consequence of increasing the product carbon footprint. In contrast, purchasing carbon allowances reduces profit only but has no impact on the optimal marketing strategy.

An alternative to a carbon cap is a carbon tax that puts a price on an organisational carbon footprint without restricting its overall emissions. Typically, a carbon tax reduces an enterprise's profit but has an ambiguous impact on the organisational footprint because the product's lower carbon footprint increases sales and, as a consequence, overall emissions.

6. Stimulating green technology adoption

The need to comply with carbon regulation may trigger investments in green technologies that allow an enterprise to produce a product with the same carbon footprint at lower cost. Research has shown that higher uncertainty about the likelihood of carbon regulation relaxes the standard condition under which the new technology is adopted. Thus, the mere threat of carbon regulation may lead to the adoption of a green technology, greener product design, and a lower organizational carbon footprint.

This insight has an important policy implication: Regulatory pressure can provide incentives for marketing managers and enterprises to do the right thing for the climate by offering greener products—the standard link from regulation to promoting innovation.

d) Key case studies

Key examples and case studies of emissions reduction and GHG emissions calculation, auditing, or reduction programs within the Australian F&A sectors in the 'toolbox' include:

i. Austral Fisheries – Australia's largest fishing company going carbon-neutral
ii. Tassal – Australia's largest aquaculture producer reporting full product supply chain emissions
iii. Harvest Road – calculating carbon footprint of bi-valve production and implementing an offset program, and
iv. The Coller FAIRR Initiative – benchmarking large seafood producers on carbon and other environmental issues.

i. Austral Fisheries – Australia's largest fishing company going carbon-neutral

Austral Fisheries is one of Australia's largest integrated commercial fishing companies. Austral catches primarily prawns fished in Australia's Northern Prawn Fishery and the prized Glacier 51 Toothfish™ from the Southern Ocean.

Austral has also been one of the leading fishing companies internationally in the fields of sustainability and carbon neutrality of its seafood products since its CEO embarked on a journey in 2016. At that time, no other seafood business was offsetting its carbon emissions. Austral's journey truly began when CEO David Carter took a once in a lifetime trip to Antarctica with some big-thinking leaders. It was here that he resolved to take Austral on a journey to offset its emissions, of which the 9 million+ litres of diesel the company burns each year were largely responsible for. Austral had always been considered a progressive company; as early adopters of Marine Stewardship Council certification and running decades-long anti-pirate campaigns. However, the scope of its emissions and operating in an environment which was seeing the firsthand effects of climate change was enough of a driver to have David and Austral thinking they should, and could, be doing more. A little over 13 months later, Austral was certified carbon neutral for their organisation and products under the Australian Government's 'Climate Active' Carbon Neutral Program and since has planted over 1 million trees through its partnership with Carbon Neutral Pty Ltd in Western Australia.

Every year, Austral plants over 220,000 mixed native species to offset its Scope 1, 2 and 3 emissions - essentially all the emissions created by the business during its operations, the emissions of all its logistics and transport (including travel) and the emissions created by its suppliers and partners throughout the process of getting Austral's products from ocean to plate.

For further information, Austral Fisheries' Australian Government Climate Active *Public Disclosure Statement (Organisation and Product) 2020*, is available for download at: https://www.climateactive.org.au/buy-climate-active/certified-members/austral-fisheries.

Figure 16 below is a representation of Austral's product process diagram and cradle-to-gate scope used in its LCA.

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Product process diagram

Figure 2 shows our cradle-to-gate scope. End-of-life emissions are not included, even though we have elected to also include 'use' in the LCA. Figure 3 shows our organisation inventory, with the yellow highlights showing those items that have been included in our Life Cycle Assessment of products. Note that all LCA emissions sources lie within the overarching organisation inventory.

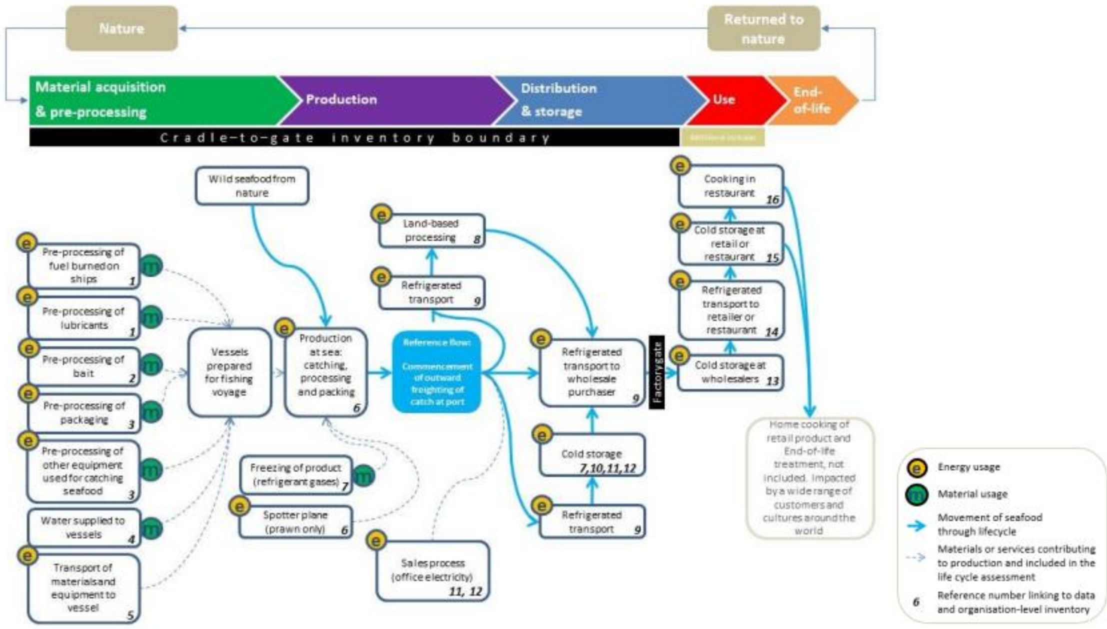

Figure 2. Process map for the production of the LCA products.

Austral Fisheries Pty Ltd 6 Climate Active

Figure 16: Austral Fisheries product process diagram used for LCA (Source Austral Fisheries, 2021)

The above diagram provides an excellent guide for any F&A company wishing to establish a roadmap to assist in their data-gathering process, data they will need to calculate their GHG emissions and start building their own carbon emissions profile.

> In his TEDx talk, Austral Fisheries CEO David Carter explains how he made his entire business carbon neutral in just 402 days. He explains why and how he did it, and how you can go carbon neutral too. Austral Fisheries has been carbon neutral since 2016 – where he once believed climate change was a taboo topic, he now knows it is all about risk and money – a language business understands perfectly.
>
> www.ted.com/talks/david_carter_don_t_wait_for_permission_to_go_carbon_neutral

A Seafood Source article on Austral and carbon provides additional information 'Austral Fisheries achieves hefty premium on first carbon-neutral toothfish and shrimp' https://www.seafoodsource.com/news/environment-sustainability/austral-fisheries-achieves-hefty-premium-on-first-carbon-neutral-toothfish-and-shrimp

ii. Tassal – Australia's largest aquaculture producer reporting full product supply chain emissions

Tassal Group is the largest vertically integrated salmon and prawn grower, and seafood processor in Australia. With more than 30 years' experience in salmon farming in Tasmania, Tassal's transfer of experience and innovation in salmon farming to tiger prawn farming is a significant achievement in the aquaculture industry.

Tassal's 2021 Sustainability Report (released October 2021) represents a benchmark in sustainability reporting for the aquaculture industry but also for any animal protein business in Australia. In the FAIRR 2021 global Protein Producer Index, Tassal came 14th (8th in aquaculture) and the highest of any Australian company.[28] In the area of climate change and carbon neutrality, Tassal has stated commitments to:

- aspire to be net zero by 2050, and are currently assessing science-based datasets to set a climate roadmap to 2030
- Establish flagship carbon neutral farm program - one salmon farm and one prawn farm
- Spend $60 million over three years on initiatives and R&D to reduce the impact of climate change on operations.

Tassal reports its energy consumption and greenhouse gas (GHG) emissions to the Commonwealth Government annually under the National Greenhouse and Energy Reporting (NGERS) scheme. By 31 October each year, Australian corporations that meet certain thresholds must report their emissions and energy information under the NGERS scheme. Scope 1 and 2 emissions are reported, as well as net energy consumed (GJ). The Clean Energy Regulator then publishes reported greenhouse gas emissions and net energy consumption for all registered corporations by 28 February each year.

Tassal is also one of the first aquaculture companies to document its full product supply chain carbon emissions, significantly providing a carbon intensity for its feed inputs. The report provides calculations of total carbon footprint for its salmon (12 kg CO_2-e per kg fish) and prawns (11 kg CO_2-e per kg prawns) benchmarked against chicken, pork, and beef.

TASSAL SALMON AND TROPIC CO PRAWNS PERFORM WELL WHEN COMPARED TO OTHER LAND BASED PROTEINS

	tassal	SALMON LAND-BASED RAS IF BASED IN NSW	SALMON LAND-BASED RAS IF BASED IN TASMANIA
PROTEIN RETENTION	28%	28%	28%
FEED CONVERSION RATIO (FCR)	1.3	1.1[1]	1.1[1]
EDIBLE MEAT PER 100KG FEED	48kg	48kg	48kg
CARBON FOOTPRINT (KG CO_{2-e}/KG EDIBLE MEAT)	12kg	49kg[2]	18kg[2]

1. FCR of 1.1 based on a 10% improvement of FCR in RAS systems
2. The carbon footprint of land-based grow out RAS has been estimated using publicly available production volumes and energy use values for existing land-based RAS grow-out operations. We have created hypothetical scenarios of land-based RAS facilities, one located close to market in NSW and the other in Tasmania using current feed composition and emission factors for each state

2021

	tassal	Tropic Co			
PROTEIN RETENTION[2]	28%	32%	37%	21%	13%
FEED CONVERSION RATIO (FCR)	1.3	2.1	1.6[3]	3.1[4]	8.0[2]
EDIBLE MEAT PER 100KG FEED[5]	48kg	47kg	39kg	19kg	7kg
CARBON FOOTPRINT (KG CO_{2-e}/KG EDIBLE MEAT)	12kg	11kg	7kg	13kg	66kg

1. All data presented for Tassal and Tropic Co based on raw data provided by Tassal
2. Based on global average taken from Fry et al (2018) Feed conversion efficiency in aquaculture: do we measure it correctly? Environ. Res. Lett. 13 024017
3. Based on average for Australian grown broilers taken from https://www.chicken.org.au/facts-and-figures/
4. Based on average for Australian grown pork taken from http://porkcrc.com.au/wp-content/uploads/2016/06/4C-117-Fianl-report.pdf
5. Based on global average taken from http://www.fao.org/gleam/results/en/#c300947 converted from kg protein to kg edible meat using FSANZ Australian Food Composition Database https://www.foodstandards.gov.au/science/monitoringnutrients/afcd/Pages/default.aspx

1. https://kb.rspca.org.au/knowledge-base/what-are-farmed-atlantic-salmon-fed/

TASSAL GROUP SUSTAINABILITY REPORT 2021 14

Figure 17: Extract from Tassal's 2021 Sustainability Report

Tassal has also reported its work on reducing the carbon intensity of feeds used in its businesses and indicates that:

> *'[its] primary feed supplier has an ambition to achieve a reduction of 30% Scope 1 and 2 emissions by 2030 with a 2018 baseline. In addition, under the Science Based Targets initiative, they have committed to a 58% reduction per unit of value-added product by 2030 in GHG emissions across their supply chain with a 2018 baseline.'*

	TOTAL CARBON FOOTPRINT OF FEED (CO_{2-e}/KG)
CY18	5.79
CY19	5.08
CY20	4.59

Figure 18: Reported Total Carbon Footprint of Feed (CO2 - 2/kg) - Tassal Limited 2021

[28] See FAIRR, at: https://dev.fairr.org/index/company-ranking/

Tassal isn't the only large salmonid producer with an increasing focus on emissions. Huon Aquaculture, as part of their broader *JBS Sustainability Strategy* has adopted ambitious decarbonisation goals. Most notably Huon propose to reduce their Scope 1 and 2 emission intensity 30% by 2030, to reach 60% renewable electricity by 2030 and to achieve net-zero GHG emissions by 2040 – through a reduction strategy – not by purchasing offsets.

iii. Harvest Road – calculating carbon footprint of bi-valve production and implementing an offset program

In January 2021, Harvest Road Oceans (HRO) also certified their mussel, akoya and rock oyster products as carbon neutral with the 'Climate Active' Carbon Neutral Program. HRO's drive to reduce carbon emissions and achieve carbon neutrality originated at the top of the organisation, from the Andrew and Nicola Forrest-led Tattarang Group. Carbon emissions reduction and carbon neutrality are corporate-wide initiatives across the whole Tattarang Group and form an integral part of the values, sustainability and innovation at the core of HRO's operations. Taking responsibility for their carbon footprint and ensuring their seafood products are produced in the most responsible way, all while protecting the oceans.

a) Benefits of carbon neutral certification

Certification from a recognised program that allows HRO to showcase sustainable aquaculture and by choosing to use the Climate Active logo on all their tags and packaging, as well as on some of their communications, allows consumers to choose to purchase sustainable shellfish products. HRO report positive feedback from consumers, and while there is existing consumer awareness that shellfish is a low-carbon product, the Climate Active carbon neutral certification and consumer labelling provides an additional benefit.

b) Achieving carbon neutral certification: emissions reduction and offset projects

HRO is reducing emissions through innovation and investment in energy-efficient equipment and integrated supply chains to future-proof production models. Working towards minimising all carbon outputs throughout the entire business, with potential to influence and work with their up and down-stream supply chain for accurate emissions data gathering, and emissions reduction opportunities.

HRO's Climate Active *Public Disclosure Statements (Product) 2021* https://www.climateactive.org.au/buy-climate-active/certified-members/harvest-road outlines their emissions reduction strategy and commitments, which include:

- Reduction in fuel consumption with new larger vessels that reduce the number of trips to and from the mussel leases
- Integrated development at the Albany shore base for akoya and oyster production, which is reducing local freight, staff travel and a reduction in boat movements
- Investments in more efficient oyster handling technology, which reduces the vessel time on the leases per production unit.

While HRO works toward reducing their carbon emissions, they have chosen to purchase offsets with the gold-standard Yarra Yarra Biodiversity Corridor project in Western Australia's wheatbelt.

c) Harvest Road Ocean's view on certification

Harvest Road recommends carbon neutral certification to any fisheries and aquaculture business. They chose Climate Active as it's backed by the Australian Government and is regarded as one of the most robust certification programs in the world. Consumers are increasingly environmentally aware and seeking climate-positive solutions so they can be certain what they are eating has the right impact on the planet.

Scott Strachan, Sustainability Lead at Harvest Road Oceans, says '*achieving carbon neutral certification starts with dedicating some time to undertake an in-house carbon audit, something every company should be able to undertake. Gathering accurate third-party Scope 3 emissions may initially prove challenging however Scope 1 and 2 emissions data such as electricity use, and fuel purchases and consumption is information that every company already has*'.

iv. The FAIRR Initiative – benchmarking large seafood producers on carbon and other environmental issues

Organisations such as The FAIRR Initiative are scrutinising large seafood producers over a range of environmental issues, GHG and climate change being one of the top ones.

The FAIRR Initiative is a collaborative investor network that raises awareness of the environmental, social and governance (ESG) risks and opportunities brought about by intensive animal agriculture. FAIRR helps investors to identify and prioritise these factors through focussed research, provided to investors to integrate into their active stewardship and decision-making processes.

- Shallow Returns? ESG Risks and Opportunities in Aquaculture (2019) https://www.fairr.org/article/shallow-returns-esg-issues-in-aquaculture/
- FAIRR Conversations: A Deep Dive into Sustainable Aquaculture (2021) https://www.fairr.org/article/fairr-conversations-a-deep-dive-into-sustainable-aquaculture/
- Managing Biodiversity & Climate Risks in Aquafeed https://www.fairr.org/engagements/sustainable-aquaculture-engagement/
- The Coller FAIRR Climate Risk Tool. The first tool of its kind to link climate impacts to the profitability of the world's largest listed meat producers.

e) Five steps to becoming a carbon neutral business

Climate change caused by human produced carbon emissions has led governments globally to implement carbon emissions schemes to reduce our carbon emissions. Change in this area is gathering pace as the scientific evidence and the impact of climate change becomes more alarming and more predictable. A sensible business response is to understand your business's exposure to carbon risk particularly in your operations and supply chain, then minimise that risk. Carbon risk includes price increases as well as legislative and regulatory change. It also makes commercial sense to demonstrate to your customers, clients, staff, and potential recruits that your business cares about the environment and our future.

For businesses wishing to do something positive limiting climate change a great step is to become carbon neutral. This may be achieved by balancing your business's carbon emissions with an equivalent amount being sequestered or offset, along with carbon reduction.

The following is a series of steps any business can take to embark on the journey and achieve carbon neutrality:

i. Set your organisation's carbon reduction targets and goal
ii. Audit your business's carbon footprint
iii. Act on opportunities to reduce your carbon emissions
iv. Offset your remaining carbon emissions
v. Evaluate progress and repeat from step 2.

Further detail on these steps is provided below.

i. Set your organisations carbon reduction targets and goal

Reducing your business's carbon emissions and becoming carbon neutral requires leadership at the top level of your organisation and a commitment to your business taking responsibility for its contribution to climate change.

For example, your company sets a goal to be carbon neutral in five years:

Year 1 - target 20% reduction in baseline emissions via energy efficiency actions or carbon offsets

Year 2 - target 40% reduction in baseline emissions via energy efficiency actions or carbon offsets

Year 3 - target 60% reduction in baseline emissions via energy efficiency actions or carbon offsets

Year 4 - target 80% reduction in baseline emissions via energy efficiency actions or carbon offsets

Year 5 - target 100% reduction in baseline emissions via energy efficiency actions or carbon offsets.

ii. Audit the carbon footprint of your business

Establishing a clear picture of your organisations' carbon emissions or carbon footprint enables you to apply the targets in real numbers. The carbon footprint is a measurement (detailed or approximate) of a business's:

- Scope 1 - Direct carbon emissions from owned or controlled sources
- Scope 2 - Indirect carbon emissions from key indirect sources (i.e. purchased electricity)
- Scope 3 - Indirect carbon emissions from all other indirect sources (i.e. emissions resulting from production of purchased materials, employee travel, and other outsourced activities).

Taken together, these constitute your emissions inventory. The emissions inventory contains your main sources of emissions and therefore identifies your opportunities for abatement and covers all areas of your business including energy use, operation of stationary equipment, transport, supply chain engagement and waste generation.

a) The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard

An accepted carbon footprint calculation methodology follows the Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard, produced by the World Resources Institute and the World Business Council for Sustainable Development. The GHG Protocol introduces the concept of 'Scope' as a means of defining the difference between direct and the two types of indirect carbon emissions.

b) Overview of scopes and emissions across a value chain.

Identifying and calculating your Scope 1 & 2 emissions is the base of your carbon audit.

(1) Scope 1

Direct emissions produced by the daily operational activities of your small business, where the emission sources are directly owned or controlled by your small business:

Examples include:

- diesel fuel – for fishing boats, support vessels, tenders, and runabouts, as well as land vehicles and Petrol or gas consumption – in boats, vehicles, generators and LPG for cooking, heating

- refrigerant fugitive emissions - type, quantity and cost of refrigerant used to recharge heating, ventilation, and air-conditioning (HVAC) equipment. Aquaculture operations in ponds may also need to calculate emissions associated with gaseous emissions from the ponds.
- fuel used and paid for by your small business when you or your staff or contractors travel in your small business vehicles for business purposes only. [Note that travel costs incurred by your use of hire cars or taxis are included as Scope 3 emission sources. Staff personal travel is omitted from scope since travel between home and office is assessed to be independent of the activities of your small business].

(2) Scope 2

Indirect emissions produced by the on-site consumption of electricity (electricity units to be in kWh).

Scope 1 and 2 emission sources form the mandatory organisational boundary for the accounting and reporting of GHG emissions. Scope 3 emissions occur further along the value chain from sources not owned or controlled by your small business. Note that for aquaculture operations, the majority of GHG emissions can fall within Scope 3.

(3) Compile your Scope 1 & 2 inventory using one of the FRDC 2020/089 self-assessment emissions calculator tools

To assist you to compile your Scope 1 and Scope 2 emissions inventory you can also calculate your direct (Scope 1) and electricity indirect (Scope 2) emissions by using the Clean Energy Regulator's National Greenhouse and Energy Reporting Scheme, where there are links to the NGERS Calculator, or one of the self-assessment tools developed for this project, which are based on the NGERS calculator.

(4) Scope 3

Indirect emissions produced as a result of business activities, but where you have no ownership and cannot control the emissions. Examples include:

- the volumes of feeds fed to your fish, prawns, or other crustaceans in aquaculture operations, or amount of bait used in your fishing operations
- disposal of waste and products at end-of-life (non-recyclables) generated in conducting your small business. This accounts for emissions generated (transport, etc.) during off-site disposal by a third party
- water used (L or m^3) in conducting your small business. This accounts for emissions generated during pumping and sewerage treatment, etc. by a third-party
- your business-related domestic and international flights
- travel costs incurred by your business use of hire cars or taxis
- expenditure for telecommunications, internet, office equipment and third-party services
- extraction, production, and transportation of purchased fuels and other purchased materials or goods
- generation of electricity that is consumed in transmission
- activities outsourced to third parties
- professional services, including the activities of your employees.

(5) Compile your Scope 3 emissions inventory

If your Scope 3 emissions are incurred by feeds or bait, you will need information from your feed supplier company or bait provider. If your bait supplier has not (yet) calculated their emissions, they will be able to calculate their emissions using the self-assessment fishery tool developed as part of this project, or you may need to calculate your bait emissions yourself if your supplier is unable to provide to you.

Your feed supplier will likely be able to provide you with accurate emissions data for your purchased feed. If your feed supplier is not able to provide emissions data, the self-assessment aquaculture tools provide ‘best guess’ estimates for feed emissions.

In addition, if your enterprise undertakes a lot of business travel or generates waste, you can calculate your other indirect (Scope 3) emissions by exploring the National Greenhouse and Energy Reporting Scheme, or for business travel, you can calculate your other indirect (Scope 3) emissions by using the Carbon Trust’s Business Carbon Footprint Calculator.

Other calculators are available on the internet, as of yet there are no standards for calculating all the Scope 3 emissions of your small business.

iii. Act on opportunities to reduce your carbon emissions

As a result of your conducting a carbon audit of your business you will have a detailed understanding of those parts of your business that are contributing to your carbon emissions and a sense of where to start acting on these to reduce your carbon emissions.

The following actions can provide you with suggestions and opportunities to lower the carbon emissions of your business:

a) Fishing enterprises

Fuel consumption, conservation and investigating alternative fuel use. Diesel fuel consumption reduction opportunities may include:

- changes to vessel design
- motor efficiencies
- adjustments to operating procedures
- gear/nets efficiency

Also lowering transport costs and carbon emissions with fuel and vehicle efficiencies.

b) Aquaculture enterprises

- Feed carbon intensity
- Energy use (on water) and diesel fuel consumption

c) Fishing and aquaculture processing/office

- building thermal efficiency
- electricity (renewables)
- power down measures
- waste management
- water conservation
- travel

iv. Offset your remaining carbon emissions

Energy efficiency actions may not be sufficient to generate all the emissions reductions required to meet your target. In these instances, carbon offsets can be used. The following two approaches are common:

1. Purchase Green power – Switch the consumption of your electricity to a renewable source (See our Buy Renewable Electricity action).
2. Offset your remaining emissions. A quick, effective and popular way to address the many tonnes of greenhouse gases we emit is to pay an organisation to offset these by, for example, planting enough trees to absorb our emitted CO_2. Organisations that provide this service include, and are not limited to:

   - GreenFleet - non-profit - approximately $18 per tonne of CO_2 offset
   - Carbon Neutral - non-profit - with multiple project offerings to invest in, cost per tonne of CO_2 offset varies across projects.

A more effective and permanent (yet more expensive) way to offset your emissions is through investments in renewable power generation, which trades your fossil fuel use against reduced fossil fuel use elsewhere.

   - ClimateFriendly - company - approx. $25 per tonne of CO_2 offset

Offsets should not be a long-term substitute for reducing the CO_2 emitted in the first place. In the short-term offsets may be very useful in helping a business become carbon neutral while it changes its business practices and works toward reducing emissions.

v. Evaluate progress and repeat

Regular evaluation of the process and actions taken will aid future efforts and actions where emissions can be reduced and offset. In addition, it will build knowledge of successful approaches and pitfalls to ensure that the next cycle is more effective than the last. For example, future equipment purchases (i.e. cars and plant) can be planned to deliver future efficiency gains.

Additional resources and information on saving power is available from the following sites:

- Environment & Heritage - Sustainable Business (NSW)
- The Environment and your Business (QLD)
- Public Utilities Office (WA)
- Energy SA (SA)
- Resource Smart (VIC)

5. Conclusions

a) Drivers for further information on GHG emissions

Drivers and needs for further information on energy use and greenhouse gas (GHG) emissions in the Australian fisheries and aquaculture sectors include:

- greatly increased **stakeholder scrutiny** on fisheries and aquaculture, and seafood products – from government, NGOs, shareholders, and consumers.
- the need for **GHG baselines** for the F&A sectors, against which further performance can be measured (and potentially benchmarked against other food production sectors).
- commercial imperatives for the F&A sectors to provide clear, disaggregated, determined and differentiated assessment of its GHG contributions within 'Agriculture' which is currently a large, aggregated sector and dataset.
- a need for companies, SMEs, and individuals to be able **to measure before managing their energy use and GHG emissions**, and
- development of more and better-quality **data** to drive **new opportunities for the F&A sectors,** and to continue to underpin the **competitiveness** of seafood in **consumer protein decision-making** and food selections.

b) Program 1: energy use and greenhouse gas (GHG) profile of Australian Fishing and Aquaculture sectors

i. GHG profiles of the Australian F&A sectors

Summaries of the GHG emissions profiles of Fishing and Aquaculture and individual industries are provided.

The wide range of species, catching and growing methods in the Australian F&A sectors, provides a complex matrix of energy usage and subsequent GHG emissions profiles. **Table 15** provides an overview of Australia's largest fisheries (wild catch and aquaculture) by GVP, their catch/production methods and an indication of the emissions scopes and relative importance of the emissions.

Table 15: Summary matrix of major species, production methods and GHG scope emissions profiles

Rank GVP	*Species/Fishery*	*Catch/ production technique*	*Aquaculture ($1.6b GVP) (51% GVP)*			*Wild catch ($1.58b) (49% GVP)*		
	Emissions type		**Scope 1**	**Scope 2**	**Scope 3**	**Scope 1**	**Scope 2**	**Scope 3**
1	Salmonids	Coastal cage culture	Medium	Low	High	n/a	n/a	n/a
2	Rock lobster	Traps/pots	n/a	n/a	n/a	High	Medium	Medium
3	Other finfish	Trawl, nets, line	Low	Medium	Low	High	Low	Low
4	Prawns	Trawl & pond culture	Low	High	High	High	Low	Low
5	Other crustaceans/molluscs	Traps, pond, coastal lines	Medium	Medium	Medium	Medium	Low	Low
6	Abalone	Hand caught, tank culture	Low	High	Medium	Medium	Medium	Medium
7	Tuna	Cage culture/ranching, line	High	Low	High	Med	Low	Low
8	Edible oysters	Coastal culture	Low*	Low	Medium	n/a	n/a	n/a
9	Other NEI (barramundi)	Pond culture, cage culture	Low	High	High	n/a	n/a	n/a

** can also be a sink*

A compilation comprised of both top-down data provided in the National Inventory by Industry Sector (NIBES), and bottom-up industry and anecdotal data, has enabled a summary of likely GHG emissions for the major industries within the F&A sectors to be prepared.

Table 16 provides a summary of the emissions profiles of the top F&A seafood industries/species, and **Table 17** categorised as Scope 1, Scope 2, and Scope 3.

Table 16: Summary of GHG emissions Australian F&A sectors

Fishery/ species (Ranked by production volume)	Production method	Sector Fuel Usage (L)*	Fuel		Refrigerants		Purchased Power		Purchased Feed/ Bait		Processing		Transport		Aquatic N2O		Totals		% of total F&A	Notes
			kg CO^2-e per kg	Sector (t CO^2-e)	kg CO^2-e per kg	Sector (t CO^2-e)	kg CO^2-e per kg	Sector (t CO^2-e)	kg CO^2-e per kg	Sector (t CO^2-e)	kg CO^2-e per kg	Sector (t CO^2-e)	kg CO^2-e per kg	Sector (t CO^2-e)	kg CO^2-e per kg	Sector (t CO^2-e)	kg CO^2-e per kg	Sector (t CO^2-e)		
Salmonids (Farmed)	Aquaculture - Cage culture		1	66,015	0.01	660	0.6	39,609	4.59	303,009	0.5	33,008	1	66,015	0.8	52,812	**8.5**	**561,128**	37%	1
Sardines	Fishing - Purse seine		0.5	21,139	0.01	423	0.3	12,683			0.5	21,139	0.3	12,683			**1.6**	**68,066**	4%	2
Other finfish	Fishing - Netting		2	124,560	0.2	12,456	0.8	49,824			0.5	31,140	1	62,280			**4.5**	**280,260**	18%	3
Prawns (wild catch)	Fishing - Trawl	27,076,852	4.2	73,649	0.2	3,528	0.8	14,112			0.5	8,820	1	17,640			**6.7**	**117,749**	8%	4
Rock Lobsters	Fishing - Pots	12,145,860	4.1	33,037			0.8	6,402	0.8	6,402	0.5	4,001	5	40,010			**11.2**	**89,851**	6%	5
Tuna (Farmed)	Aquaculture - Cage culture		1	8,345	0.01	83	1.6	13,352	12	100,140	0.5	4,173	2	16,690	0.8	6,676	**17.9**	**149,459**	10%	6
Oysters (Farmed)	Aquaculture - Baskets	5,990,655	2.0	16,295	0.01	83	0.8	6,676			0.5	4,173	1	8,345	0.8	6,676	**5.1**	**42,248**	3%	7
Scallops	Fishing - Dredged		4	26,460	0.01	66	0.8	5,292			0.5	3,308	1	6,615			**6.3**	**41,741**	3%	8
Barramundi (Farmed)	Aquaculture - Pond/cage/ RAS		1	3,427	0.01	34	5.6	19,191	4.59	15,730	0.5	1,714	1	3,427	0.8	2,742	**13.5**	**46,265**	3%	9
Sharks/ Rays	Fishing - Netting / longline		2	10,062	0.2	1,006	0.8	4,025	1	5,031	0.5	2,516	1	5,031			**5.5**	**27,671**	2%	10
Prawns (Farmed)	Aquaculture - Pond/RAS		0.5	3,370	0.01	67	6.4	43,136	6	40,440	0.5	3,370	1	6,740	0.8	5,392	**15.2**	**102,515**	7%	11
Subtotals				**386,358**		**18,408**		**214,302**		**470,751**		**117,359**		**245,476**		**74,298**		**1,526,951**		

Notes:

* If data available via ATO data

1. **Salmonids (Farmed)** – Feed carbon intensity 4.59 kg CO_2-e per kg, based on Tassal Limited, 2021 Sustainability Report, page 38 'Total Carbon footprint of feed (CO_2-e/kg)'. Note that Tassal Ltd estimates total carbon footprint is 12kg CO_2-e/kg edible salmon meat) (page 14 of 2021 sustainability report).
2. **Sardines** – Note - Sardines are a special case, as the catch is predominantly utilised as feed for the tuna aquaculture industry in South Australia. The sardine fishery itself has a relatively low carbon footprint, it increases significantly when sardines are caught, processed, stored and then fed to farmed tuna.
3. **Other finfish** – Fuel analogue based on industry estimate for northern fisheries.
4. **Prawns (wild catch)** – High fuel use intensity. But is mitigated to some extent by no electricity and feed inputs, that create a relatively lower GHG emissions profile than for farmed prawns (source: Austral Fisheries, 2021).
5. **Rock lobsters** – Transport estimate based on long haul flight to northeast Asia.
6. **Tuna (farmed)** – Feed intensity based on *Macleod et al*. High use of sardines (see note above) creates a high GHG footprint related to feed. Power intensity based on Macleod and on existing prawn farm case studies.
7. **Oysters (farmed)** – n/a
8. **Scallops (dredged)** – Fuel intensity estimated, similar to prawn trawl.
9. **Barramundi (farmed)** – Feed carbon intensity based on salmon (source: Tassal Limited, 2021 Sustainability Report, page 38 (Best Case).
10. **Sharks/rays** – Fuel analogue based on industry estimate for northern fisheries (Austral).
11. **Prawns (Farmed)** – Feed intensity based on *Macleod et al*. Power intensity based on *Macleod et. al.* and on existing prawn farm case studies.

Table 17: Australian aquaculture & fisheries sector emissions (by scope) and segment (2019-20)

Sector Production					Scope 1					Scope 2				Scope 3				
	GVP $	Vol t	Emissions (tot)	CO^2-e/kg	Fuel	Refrigerant	N_2O	Subtotal	% of tot	Power	Process	Subtotal	% of tot	Feed/bait	Transport	Process	Subtotal	% of tot
Fishing	**1,201**	**143,554**	**625,337**	**4.4**	288,906	17,479		306,385	49%	92,338		92,338	15%	11,433	144,259	71,094	226,786	36%
%	**46%**	**61%**	**41%**															
Sardines	$30	42,277	68,066	1.6	21,139	423	0	21,561	32%	12,683	0	12,683	19%	0	12,683	21,139	33,822	50%
Other Finfish	$372	62,280	280,260	4.5	124,560	12,456	0	137,016	49%	49,824	0	49,824	18%	0	62,280	31,140	93,420	33%
Prawns WC	$233	17,640	117,749	6.7	73,649	3,528	0	77,177	66%	14,112	0	14,112	12%	0	17,640	8,820	26,460	22%
Rock Lobsters	$521	8,002	89,851	11.2	33,037	0	0	33,037	37%	6,402	0	6,402	7%	6,402	40,010	4,173	50,584	56%
Scallops	$18	6,615	41,741	6.3	26,460	66	0	26,526	64%	5,292	0	5,292	13%	0	6,615	3,308	9,923	24%
Shark rays	$27	6,740	27,671	4.1	10,062	1,006	0	11,068	40%	4,025	0	4,025	15%	5,031	5,031	2,516	12,578	45%
Aquaculture	**1,390**	**92,872**	**901,614**	**9.7**	97,452	929	74,298	172,678	19%	121,964	46,436	168,400	19%	465,720	101,217	0	566,937	63%
%	**54%**	**39%**	**59%**															
Salmonids	$890	66,015	561,128	8.5	66,015	660	52,812	119,487	21%	39,609	33,008	72,617	13%	303,009	66,015	0	369,024	66%
Tuna	$137	8,345	149,459	17.9	8,345	83	6,676	15,104	10%	13,352	4,173	17,525	12%	100,140	16,690	0	116,830	78%
Oysters	$137	8,345	42,248	5.1	16,295	83	6,676	23,054	55%	6,676	4,173	10,849	26%	6,402	8,345	0	14,747	35%
Barra	$91	3,427	46,265	13.5	3,427	34	2,742	6,203	13%	19,191	1,714	20,905	45%	15,730	3,427	0	19,157	41%
Prawns	$135	6,740	102,515	15.2	3,370	67	5,392	8,829	9%	43,136	3,370	46,506	45%	40,440	6,740	0	47,180	46%
TOTALS	**2,591**	**236,426**	**1,526,951**	**6.5**	386,358	18,408	74,298	479,063	31%	214,302	46,436	260,738	17%	477,153	245,476	71,094	793,723	52%

* fisheries information source: *Steven, AH, Dylewski, M and Curtotti, R 2021, Australian fisheries and aquaculture statistics 2020, Fisheries Research and Development Corporation, ABARES, Canberra, August.*

ii. Key highlights

Key highlights from this project are:

- The GHG emissions of the Australian F&A sectors as represented by the top 11 fisheries constituting 82% of all Australian seafood production (2019-20) is estimated to be approximately **1.5 Mt CO_2-e**. This equates to an **average GHG intensity of 6.5 kg CO_2-e per kg of Australian produced seafood** from fishing and aquaculture. This is more than double the NIBES reported emissions for the F&A sectors, (which admittedly does not include provisions for Scope 2 and Scope 3 emissions).
- Of the overall emissions in the two sectors, **Aquaculture** constitutes 900 kt CO_2-e or **59%** of the emissions, whilst Fishing produces 625 kt CO_2-e (**41%** of the total). Average **GHG intensity** for **Fishing** was estimated at nearly **4.4 kg CO_2-e per kg** of catch, whilst average intensity for **aquaculture** was estimated at **9.7 kg CO_2-**e.
- Of the total emissions profile of both sectors, **purchased feed** (and bait) constituted the highest GHG emissions component of the entire profile, at just over 470 kt CO_2-e (31%), followed by (diesel) **fuel use** at just under 390 kt CO_2-e (25%) and **transport** about 245 kt CO_2-e (16%).
- By production volume, the **largest industry GHG contributor** is the **salmonids industry** with 560 kt CO_2-e constituting 37% of total emissions whilst producing 28% of the volume and 34% by value of all domestic seafood production. The next most significant are the **Other Finfish** industry group with 280 kt CO_2-e (~18%) producing 22% of volume and 12% by value of domestic seafood production, **tuna farming** which produces 150 kt CO_2-e (nearly 10%), **prawn trawling** 118 kt CO_2-e (~8%), and **prawn farming** 102 kt CO_2-e (7%).
- In terms of emissions intensities, **farmed tuna is the highest GHG intensity product**, with nearly 18 kg CO_2-e per kg of product produced, thanks to a combination of the fuel used to catch the juvenile fish, GHG intensive feed inputs, and high transport costs to deliver products to distant export markets.[29] The next most GHG intensive product is **farmed prawns** with 15.2 kg CO_2-e and **farmed barramundi** at 13.5 kg CO_2-e per kg of product produced. **Rock lobster** is the next most GHG intensive product at just over 11 kg CO_2-e per kg, and **salmon** at 8.5 kg CO_2-e per kg of fish produced. However, industry leader Tassal estimates a total carbon footprint of its *edible salmon meat* of 12kg CO_2-e/kg, which also accounts for processing and all full post processing factors including storage, transport, and cooking. [30]
- Significantly, **the predominant emissions for the F&A sectors are Scope 3**, totalling 52% of the total profile, of which 45% are derived from feed/bait, transport, and processing related costs, followed by Scope 1 emissions (fuel and fugitive emissions from refrigerant gases and N_2O) representing 31%.

Fishing highlights

- The **fishing industry contributes about 41% of the F&A sectors' total emissions** profile. Nearly half is Scope 1 emissions, principally fuel combustion, followed by Scope 3 emissions dominated by transport and secondary processing. Scope 2 emissions (electricity purchased) was the third highest aggregation. However, as 'processing costs' are captured in both Scope 2 and Scope 3 emissions profiles, the **overall ranking of emissions for the fishing industry** are: 1) **fuel** combustion 2) **processing** and 3) **transport** (of primary and secondarily processed products).
- An estimate of total GHG emissions for the Australian fishing sector indicates that the top six industries examined (sardines, Other Finfish, wild-caught Prawns, Rock Lobsters, Scallops and Sharks/Rays) produces approximately 625 kt CO_2-e with an average GHG intensity of nearly **4.4 kg CO_2-e per kg**. The largest contributors are the Other finfish, Prawn trawling, and Rock lobster catching industries. Within the overall fishing sector, fuel consumption constitutes 46% of total

[29] Tuna intensity is even higher if the GHG emissions of sardine fishing are included.
[30] Industry leader Tassal, estimates total carbon footprint is 12kg CO2-e/kg edible salmon meat

emissions and along with some refrigerant loss emissions (3%) make up Scope 1 emissions which constitute nearly half of all emissions associated with fishing.

- Within Fishing, Scope 1 emissions are the most significant, with the wild catch prawn trawling industry, Scope 1 emissions constituting 66% of the industry's total emissions, and scallops 64%, highlighting the fuel combustion driven nature of their carbon footprints. Expectedly, Scope 3 emissions from transport (23%) represent the other major contributor to the carbon footprints of the fishing industries. For the Rock Lobster industry, transport emissions plus the purchase of bait, constitute 52% of the fishery's GHG profile. For sharks and rays, which also have some bait purchase related emissions and transport, Scope 3 emissions represent 36% of the fishery's total carbon footprint. Other finfish transport emissions (whilst having a small component of bait – but not calculated) constitutes 22% whilst prawn trawling 15% of total emissions.

Aquaculture highlights

- The **aquaculture industry contributes 59% of the total F&A sectors' total emissions** profile. An overwhelming proportion (66%) of the sector's emissions are Scope 3, predominated by **feed** (principally for salmonids), which represents the single largest GHG emissions contribution from the entire Australian seafood production industry. It is also relevant to note that much of the emissions associated with these feeds is embodied in input products produced outside of Australia and imported, and therefore are not captured in our National Accounts framework or reporting. Nonetheless, as the fish are grown in Australia, the CO_2 and methane emissions from the feed application, their respiration and growth are theoretically part of the emissions data framework but are currently not calculated or reported in the National Accounts.
- Driven by the feed emissions contributions noted above, the salmonids industry is the largest GHG emitter by production volume in Australia, with a nominal emissions profile of 0.56 Mt CO_2-e, and with feed constituting 54% of the industry's emissions. Similarly, tuna, with a total emissions profile of 150 kt CO_2-e, has a high GHG embodied feed component of 100 kt CO_2-e representing 67% of the industry's total emissions and making **farmed tuna** with a GHG intensity of nearly 18 kg CO_2-e per kg of fish **Australia's most GHG intensive seafood**. Feeds utilised by the salmonid, prawn and barramundi farming operations is manufactured from products produced outside of Australia. By contrast, the tuna industry relies on Australia's second largest fishery by volume – sardines – as its feed input. While the sardine fishery has a relatively low GHG intensity of 1.6 kg CO_2-e per kg of catch, catching sardines for tuna feed has a much higher GHG intensity of 12 kg CO_2-e per kg of feed, due in part to the additional steps such as storage, refrigeration, transporting back out to the offshore tuna cages as feed, that are required to turn fished sardines into tuna feed. The GHG emissions embodied in this sardine fishing activity contributes to the high GHG intensity of tuna production, but because this feed input is also derived domestically, it is nominally accounted within the Australian GHG accounting framework and National Accounts.
- The emissions profiles of the prawn and barramundi aquaculture industries are dominated by Scope 2 emissions (purchased electricity) for production and processing, constituting 45% of the total emissions, and feeds (Scope 3) which constitute 34% and 39% respectively of total GHG emissions. Whilst Scope 3 emissions are not part of the Australian reporting framework, for the barramundi and prawn farming industries which represent nearly half of the non-salmonid aquaculture sector, Scope 2 emissions of 67 kt CO_2-e, which are 10 times that of Scope 1 emissions (fuel combustion), are currently not reported.

iii. Issues with current Australian GHG data capture, estimates & reporting for the F&A sectors

Our review has identified several issues and opportunities with both the current Australian government's procedures for GHG capture and reporting, as well as general issues for the F&A sectors related to reporting of GHG emissions.

Large components of F&A emissions in Scope 2 & 3 not captured at the fishing and aquaculture level. Most of F&A sectors' total emissions fall within Scopes 2 and 3. However, the current NIBES and National Accounts reporting for the F&A sector is predominantly around Scope 1 emissions (direct, fuel combustion as well as some fugitive gas releases) and therefore do not provide an accurate picture of the sectors' GHG footprints. Key issues associated with the Australian government's National Accounts and NIBES data collection, estimates and reporting of GHG emissions for the F&A sectors include:

- The NIBES data for the overall sector report currently reports the combined 2019 F&A sectors emissions at 713 kt CO_2-e (Aquaculture 397; Fishing 316 kt CO_2-e). Our estimates are the F&A combined GHG footprint is more in the order of **1,527 kt CO_2-e**, or 1.5 Mt CO_2-e (Aquaculture 902,000; Fishing 625,000 kt CO_2-e).
- For **Fishing**, Scope 1 emissions are nearly 50% of this total, so for this sector, accurately capturing and reporting these emissions under the current NIBES schemes, is relevant and important.
- For **Aquaculture**, Scope 1 emissions represent just 19%, so reporting under the current NIBES measures is less relevant.

NIBES data for fuel use by Aquaculture sector appears to be under-reporting. Due to the allocation of emissions to other activities. For the NIBES reporting of Scope 1 emissions from fuel use, the DISER has historically allocated fuel use in the F&A sector as 5 – 6% of total consumption by the Agriculture, Forestry & Fisheries (AFF) industries aggregation. This allocation has been based on some historical data, which may no longer be relevant. More recently, the fuel consumption allocation to the F&A sectors (and entire AFF aggregation) has been based on ABS Economic Inputs-Outputs model data and ATO Fuel Tax Credit Scheme (FTCS) reporting. However, these measures also appear to have issues, including:

- FTCS and fuel consumption for the Aquaculture sector appears to be under-reported, when correlated with production. It is unlikely that operators would not lodge or underclaim these benefits, so the lower-than-expected figures are more likely to be due to the data being mis-reported (i.e. not captured under the 'aquaculture' reporting codes, but under another category such as 'water transportation) due to how the fuel is consumed (viz. on marine vessels)'.
- ATO and NIBES data is currently not collecting fuel use data for fishing vessels purchasing fuel outside of Australia (in accordance with international guidelines around the reporting of international bunker fuels).

Scope 2 emissions not adequately considered or captured at the fishing and aquaculture level. Scope 2 emissions (from purchased electricity) for the F&A sectors, do not appear to be adequately considered or captured under the NIBES reporting of Australian industry GHG emissions. Specifically:

- it is unclear how the F&A sectors are allocated proportions of the overall Scope 2 emissions for the AFF sector
- Nonetheless, reported Scope 2 emissions for the Aquaculture sector (derived from electricity consumption) may also be under-estimated in the entire NIBES inventory due to a lack of data on actual (versus estimated) electricity use in the sector. Electricity consumption in the land-based pond aquaculture is significant (we estimate it may represent up to 45% of total emissions for the prawn and barramundi farming industries).
    - Purchased electricity use for the large cage culture industries is associated with processing and hatchery operations, and emissions therefore appear to not be captured under Aquaculture (and may be captured and reported under other classifications such as 'food processing'). For example, Tassal Group, the largest aquaculture producer in Australia reports Scope 2 emissions (2021) being nearly 40% of its total Scope 1 and 2 emissions.
    - Calculating Scope 2 (and Scope 1) emissions intensities for aquaculture industries with small numbers of reporting companies on a state-by-state basis, such as barramundi and lobsters, is more difficult because of anonymisation of their production data for confidentiality reasons.

Fugitive emissions may be inappropriately and inadequately reported. Under the National Accounts and NIBES reporting, GHG emissions are reported (under Scope 1) for fugitive emissions – specifically nitrous oxides (N_2O). As discussed below, the methodologies used may not be appropriate:

Wetlands related emissions & calculation methods need to be reassessed. Currently in the National Accounts there is reporting of emissions for the Aquaculture sector, calculated under methods for Land Use, Land Use Change & Forestry (LULUCF) and specifically for Wetlands associated emissions. This method needs further assessment and refinement. The methodology, described as "Wetlands remaining Wetlands", is nominally a calculation of N_2O emissions from the production of finfish and crustaceans in aquaculture systems located in coastal wetland habitats – deriving from two aspects: 1) clearing of coastal wetlands (and their drying); and 2) direct emissions from ponds containing fish and crustaceans which includes N_2O but also CH_4 and CO_2. The general methods under the LULUCF and 'wetlands remaining wetlands' components are spatial, associated with the calculation of areal changes of vegetation removed or changes to the land systems which impact on them acting as emissions sources or sinks.

Currently, the methodology used by DISER:

- does not use a 'spatial 'approach and therefore does not calculate emissions associated with displaced wetlands or other areal coastal land-use changes
- uses a 'biomass' approach but which may be inaccurately applied in volume, and only calculates N_2O emissions. Currently, the method applies aquaculture 'groups of interest…that are mostly cultured in coastal wetland-based facilities… and therefore…fish production for salmonids, tuna, barramundi, and prawns' to calculate an annual N_2O emissions for all aquaculture in Australia. The method appears to be utilising a coastal wetlands method and applying a component (N_2O emissions) to all aquaculture, which is predominated by caged culture production in temperate coastal waters.

There are some relatively small but more significant areas of aquaculture emissions which could be determined to provide a better assessment of the footprint of the aquaculture industry. In the National accounts, estimates of emissions associated with wetland methane emissions, seagrass losses from dredging and enteric emissions for animals such as ostrich flocks are currently estimated. Therefore, comparatively, it should be possible to apply similar methodological principles to the aquaculture industry, to gain more accurate and meaningful data. For the land-based, pond aquaculture (predominantly in Queensland, the estimation of emissions would nominally focus on:

- area of new ponds created – which have removed coastal wetlands (mangroves, coastal marshes, etc.) removing carbon sinks
- area of existing ponds – in which coastal wetlands are not able to regenerate, and which produce GHG emissions as a result of:
  - decomposition of organic (e.g. excreted N wastes, uneaten feed) and inorganic materials (fertilisers) in the ponds which release nitrous oxides (as NO_2), but also methane (CH_4) and other volatiles, and
  - gases produced by animals in the ponds (therefore a function of the entire biomass) predominantly, carbon dioxide resulting from the respiration of the biomass, but also NO_2, CH_4 and other volatiles.

Refrigerant gas losses need to be included in fugitives reporting metrics. Refrigerant gases used in the F&A sectors which are lost from vessel or land-based chilling/freezer units to the atmosphere (Scope 1 direct emissions) and have high GWPs, are not being included in the estimates/reporting at the fishing and aquaculture level. Our estimates based on reported and anecdotal data indicate that direct refrigerant losses could constitute 3% of the total carbon footprint of the Fishing sector but appear to be much less significant for the Aquaculture sector.

Fuel Tax Credit Scheme could be better utilised to measure fuel consumption and GHG emissions. There are several improvements that could be made to the FTCS reporting for the F&A sectors, which would be beneficial for government and industry, in both measuring fuel use and efficiency and GHG reporting. Key improvements would include:

- the F&A sectors (possibly represented by the FRDC) to work with DISER and the ATO to request that the ATO meta-data retain the full BIC descriptions for businesses submitting FTCS claims, to enable more comprehensive and accurate reporting of diesel use in the Australian seafood sectors.
- The Aquaculture sector – in particular those with substantial cage culture operations – to assess whether FTCS claims being captured under aquaculture related BICS particularly for its marine vessels, or whether they are being reported under other industry classifications such as marine transportation.

Scope 2 emissions for Aquaculture – purchased power – may be better calculated by enterprises and aggregated/reported by industry associations. Scope 2 emissions from electricity purchased may be better calculated by enterprises and aggregated/reported by industry associations as it is difficult to disaggregate data within the National Accounts.

- Power purchases are significant factors in the costs of onshore aquaculture production for prawns, barramundi, and abalone. Industry studies on power use are a decade old or more and sectoral power use data for prawn farm aquaculture or barramundi farm aquaculture, are not publicly available.
- It may be more pragmatic for industry associations to encourage individual businesses within their groups, to determine their own energy usage from itemised power bills, and hence derive an 'industry estimate' of their greenhouse gas emissions.
- The GHG Calculator Tools provided as Program 2 of this study, provide some mechanisms for enterprises to calculate their own emissions, including Scope 2 emissions.

Capturing (and managing) Scope 3 emissions is critical for the F&A sectors.

- For **Fishing** – transportation and processing (third party) represent significant sources of Scope 3 emissions. (For Aquaculture more processing is done in-house so is captured as Scope 2 emissions). The use of bait also represents a significant but often overlooked component.
- For **Aquaculture** – **the use of feeds is a very significant issue**. Feed inputs are the most significant GHG contributor to the carbon footprint of the Aquaculture sector. Contemporary estimates in the available scientific literature show that **formulated feeds may represent over 50% of a farming operation's overall greenhouse gas emissions footprint**. Moreover, data for feed, which is a Scope 3 emission, has not been accounted in the National emissions profile for the Fishing Industry (aquaculture & fishing), and is a significant data issue for the aquaculture industry and businesses trying to evaluate their carbon footprint. The National Greenhouse Accounts information for the aquaculture industry emissions calculations or calculator tools, without a Scope 3 emissions assessment including feed, are inherently compromised and are probably grossly under-reporting.
- Feed companies have only recently made carbon footprint information available to aquaculture producers and these producers have also only just commenced providing this to their customers. This was due to:
  - complexities in the quantification of the embodied emissions in each of the many components of feed and stages of feed manufacture, and
  - a general focus of government on GHG emissions reporting on direct (Scope 1) and electricity (Scope 2) emissions, with Scope 3 emissions not required to be reported.
- However, some feed manufacturers, in particular the larger companies such as Skretting and Biomar, are taking significant steps in advanced carbon accounting methodologies for the raw materials used in their feeds. Several companies are now collecting primary data from suppliers and are working directly with their suppliers to improve footprints. In addition, all the major feed companies report to the Science Based Targets initiative (SBTi) where they disclose scope 1, 2 and 3

emissions on a yearly basis.[31] Some also have commenced disclosing per kilogram emissions (including scope 1, 2 and 3) in annual reports, sustainability reports and directly to customers seeking this information. It is quickly becoming more standard practice to do this and importantly, it will soon be part of the Aquaculture Stewardship Council (ASC) certification.[32]

- An accurate analysis of the carbon footprint of aquaculture operations requires adequate data on the GHG emissions profiles of all feed inputs. Industry will need to continue to work together to enable greater determination and disclosure of GHG emissions associated with feed for better reporting directly and through the product supply chain, to consumers. Standardised carbon footprint metrics for feeds may be a valuable tool for farmers to assess the carbon profiles of their products and overall, to compare seafood products against other competitive farmed protein offerings.
- Similarly, for the Fishing sector, purchased bait is an often-missed Scope 3 emissions input in the Fishing sector. It is an issue particularly for the Rock Lobster and Shark/ray fisheries. Whilst some GHG calculators include a 'bait' input component, there will probably be a greater obligation for bait producers to undertake carbon calculations and provide them to their customers (fishers), which in-turn they can incorporate the information into their own supply chain emissions calculations.

c) Program 2: Energy & GHG emissions self-assessment tools

The objective of Program 2 was to develop several tools for energy & GHG emissions self-assessment, able to be readily utilised by the Australian F&A sectors. Several tools developed and utilised overseas were reviewed.

Australian Fishing and Aquaculture Self-Assessment Tools

To satisfy the wide variety of fishing and aquaculture operations, three separate Excel-based tools were developed that will potentially cover 80% of all F&A operations in Australia. These tools cover:

- **Fisheries** – for large fleets, trawlers, purse seine vessel-based fisheries and for small vessel-based fisheries utilising traps, pots, entanglement nets
- **Offshore Aquaculture** – offshore cage grow-out operations, with onshore processing
- **Onshore Aquaculture** – land-based ponds and processing.

Outputs from the tools are presented in simple charts that demonstrates the size and relative importance of the business's key greenhouse gas emission categories. Examples of input and output screens for the GHG calculator tools developed are presented in the main body of the report.

d) Program 3: Emissions reduction opportunities in the F&A sectors: a toolbox

The key objective of Program 3 was to provide a toolbox – several different types of examples and approaches – able to be utilised by Australian F&A companies:

- as guides and incentives to reduce their energy use and GHG emissions/footprint and
- to provide information on how to present and promote these achievements with customers.

[31] See: SBTi website at: https://sciencebasedtargets.org/
[32] See: https://www.asc-aqua.org/what-we-do/our-standards/feed-standard/

i. Toolbox case studies

In the toolbox, the following examples and case studies of emissions reduction and GHG emissions calculation, auditing, or reduction programs within the Australian F&A sectors are included:

i. Austral Fisheries – making Australia's largest fishing company carbon-neutral
ii. Tassal – Australia's largest aquaculture producer reporting full product supply chain emissions
iii. Harvest Road – calculating carbon footprint of oysters and mussels, and implementing an offset program, and
iv. The Coller FAIRR Initiative – benchmarking large seafood producers on carbon and other environmental issues.

> It is possible for every farmer to benefit from the carbon market, enjoy new revenue streams, and greater business sustainability in the face of climate change. To deliver on that possibility, we must accelerate data sharing by lowering the cost of its collection and reducing the risks. We can reduce risks through approaches like Food Agility's Data Sharing Agreement template that balances risk and return, minimising the data transferred to other parties, and making datasets more interoperable. In doing so, we will secure the data needed to ground truth, cheaper more accurate predictions. There is money to be made in carbon. Who gets to make it will depend on how well we manage farm data in these vital early stages of the market's evolution.
>
> *Camilla Roberts, Chief Commercial Officer at Food Agility CRC The Food Agility CRC*[33]

[33] See: Food Agility Collaborative Research Centre (FA-CRC) at: https://www.foodagility.com/ .

6. Recommendations

1. This report has produced the first attempt at assembling a detailed picture of the energy use and GHG emissions profile of the Australian fishing and aquaculture sectors and their constituent industries. However, there are still several significant questions over the reporting in particular the results as reported in the National Accounts and NIBES, which needs to be addressed to make the profile more accurate and a reliable reflection of the sectors, and their profiles within the currently aggregated 'Agriculture' GHG emissions reporting. **It is recommended that FRDC continue to work with DISER, the Clean Energy Regulator, and the Australian Tax Office, to determine best measures for obtaining and reporting data from the F&A sectors and presenting it in the national reporting schemes.**
2. Data that are best collected at an Industry Association level – such as electricity consumption – for the Prawn and Barramundi farming industries. Such data collection also opens opportunities for the industries to explore collective and industry-wide approaches and initiatives such as: energy efficiency measures, and aggregated energy purchasing (including renewables). These pond-based producers can also provide valuable inputs to better quantify GHG emissions related to land use, wetlands, and wastewater discharge impacts on GHG emissions. **It is recommended that FRDC continue to work with the APFA and ABFA to explore measures to enable better data inputs from these industries into national reporting schemes.**
3. Establishing a national baseline of emissions for the F&A sectors has not yet been achieved but should be a priority. The F&A sectors and their industry players cannot manage what they can't measure. As a first step, the deployment of the three GHG self-assessment tools should provide a readily accessible and easy way for enterprises to start to calculate their energy use and emissions. However, the FRDC may need to provide some further support for this and monitor the use of the tools. Depending on uptake, it may be beneficial for the FRDC to support some workshops – in collaboration with Industry Associations and Fishery RACs – to assist enterprises with using tools and developing their GHG profiles. FRDC should further investigate via engagement with industry, the appetite of members to **take part in voluntary annual GHG surveys or lodgement of GHG profile results, to try to build further 'bottom-up' data which supplements the national GHG emissions inventory calculation.**
4. FRDC should seek to commit industry to a timetable to develop a comprehensive national F&A sector GHG baseline and ongoing annual reporting schedule, to provide:
   - a benchmark of emissions and
   - Annual reporting against the benchmark and other relevant comparators.
5. There is range of other carbon/GHG related issues, such as carbon offsetting, blue carbon, waste management and circular economy issues, which overlap with emissions reporting. **The FRDC should continue seeking to develop communications networks of speciality information in these areas, but also broader multi-sectoral streams to leverage the potential outcomes from these individual and rapidly evolving areas of work and thought**.

7. Extension and Adoption Plan

a) Objectives

The key objectives of the Extension and Adoption Plan (**E&A Plan**) are:

- Create awareness in the Fishing and Aquaculture (F&A) sectors of the Project and its objectives (carbon footprint of the sectors)
- Potentially elicit contact from and engagement with members of the F&A sectors who may have or be currently undertaking projects in energy use or greenhouse gas (GHG) measurement/management
- Present results and findings of the Project (via the formal Report)
- Present to F&A sectors and provide access to the carbon emissions calculators/tools for emissions review and estimation
- Present results and findings of the Project in less technical, and reader-friendly formats including FRDCs range of media channels.
- Effect changes in how energy consumption and GHG emissions data are collected, estimated, and reported in the Australian National Greenhouse Accounts and National Inventory Reports, and
- Create discussions and ongoing dialogue in the F&A sector regarding growing scrutiny and potential importance of energy/carbon footprints of seafood products.

b) Target Audiences

- Report and Tools – Primary audiences are F&A industry entities, fisheries, and seafood-related industry associations.
- Report – Findings and recommendations specifically addressed to Australian and States agencies responsible for collecting, estimating, and reporting industry energy consumption and GHG emissions
- Report findings in simple ‘message’ format – Audiences of FRDC media (*Fish* magazine, *FRDC News* monthly newsletter)
- Key recommendations (re energy use/GHG reporting) – Australian and States government agencies/departments that collect and report GHG emission and related industry data (e.g. fuel tax credit scheme data).

c) Key Messages

- Current data collection, estimation, and reporting of energy consumption and GHG emissions for the F&A sector has several technical flaws and issues
- Provide tools able to be utilised by F&A sector for measurement and assessment of energy use and GHG
- Provide information on growing importance of carbon footprints in consumer purchasing of protein/food, financial investments

d) Methods

We propose to use the FRDC’s existing extension channels and F&A industry associations for extension of the project findings, energy reduction toolkit and the GHG Calculator Tools.

- FRDC's Fish publication - with a short 'Final Report' summary notice, an 'In Brief' article and/or a feature article. To include links / information to access the GHG Calculator Tools.
- FRDC's News monthly e-publication - notice/announcement/short article in the newsletter. With links to access the tools/calculators.
- F&A Industry associations - provide the report, the tools and the tool usage guides/training to industry associations, to disseminate the tools (and report/non-technical summary) to their members.

We also propose that at the completion of the Project, we will post a short article on LinkedIn to:

- provide a summary of findings and hyperlinks to Report and associated articles (in Fish! Magazine & FRDC News).

e) Action Plan for project

#	Method	Responsibility	Completion date	During / After Project
1.	FRDC monthly e-newsletter - short article on project, May 2022 edition	FRDC	May 2022	After
2.	FRDC *Fish!* Magazine - article on project, June 2022 edition	FRDC	June 2022	After
4.	Seafood Directions, Brisbane September 13-15, 2022 Blueshift/Rob Bell: present report outcomes / tools	Blueshift	September 13-15, 2022	After
5.	Disseminate the report and tools to F&A industry associations	FRDC Extension Officers	TBD	After

f) Evaluation

Success of the plan will firstly be evaluated by:

- adoption and use of the GHG Emissions Calculator Tools and toolkit (by feedback to FRDC and industry associations, fisheries)
- implementation of feedback, recommendations to Australian and States government agencies/departments that collect and report GHG emission data (FRDC to review recommendations with relevant government departments)
- reports of F&A companies undertaking voluntary projects to measure/assess energy use/GHG projects
- (future) quantitative reports of energy use and GHG emissions and F&A sectoral trajectories.

8. Project materials developed

This project has developed three Microsoft Excel-based GHG Footprint Self-Assessment Tools for the Fishing and Aquaculture industries in Australia:

1. Blueshift Fisheries GHG Footprint Tool
2. Blueshift Aquaculture Offshore GHG Footprint Tool
3. Blueshift Aquaculture Onshore GHG Footprint Tool

The Tools are available for download on the projects page of the Blueshift Consulting website:
https://blueshiftconsulting.com.au/projects

and on the FRDC website, 2020/089 project page:
https://www.frdc.com.au/project/2020-089

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10. Appendix 1: FRDC prior research & international contemporary literature review

a) FRDC prior research

FRDC has funded several prior projects, with relevance to this project, which are summarised below.

i. FRDC Project 2005/239 Fishing Energy Efficiency Review[34]

Key findings of Project 2005/239 were that the role of **energy audits** and benchmarking was acknowledged as a key tool. And a review of **energy efficiency** in fisheries uncovered many related matters, technically complex issues, and **much uncertainty in trying to identify economically rational strategies** for improving energy efficiency in fishing (and the fishing industry's viability), which included:

- Arrangements to make available biodiesel at fishing ports
- Discussions with Hampidjan representatives regarding the performance, availability and cost of 1.1mm Dyneema netting for prawn trawling
- Appropriate fuel meters so that fuel consumption can be monitored in real time and operators/investigators can start learning a lot more about how the fuel is used and may be saved. Only one manufacturer of general-purpose fuel meters for diesel engines could be found. These were manufactured by Flowscan in the US.
- Potentially beneficial products or ideas (hydrogen injection, bingo gas, skewed propellers, propeller boss cap fins) including enquiries regarding implementation and costs for fishing boats.
- Propulsion systems and performance prediction software; with quotes for commercial products.
- Optimum propeller size selection.
- Waste heat recovery for diesel engines (compound cycles, turbo generators, Stirling cycle engines, thermoelectric generators).
- The pros and cons and economics and practicalities of hydrogen injection, alternative engines, fuel/production-processes (producer gas or syngas, Fischer-Tropsch process)
- Alternative energy - wave and wind (horizontal axis, vertical axis, the disk-style wind turbine).
- Hull design, especially planning hulls and stern wedges.
- Better winch control methods for trawlers to improve fuel efficiency when experiencing side winds and currents.
- The potential advantages of positive traction for trawling (Positive refinements for the batwing otter boards and otter boards with movable fins giving L/D = 6.)
- The benefits of co-management.

On the issue of impacts of increasing fuel costs and technologies suitable for fisheries that potentially improve energy efficiency or reduce the cost of fuel industry of adopting engine modifications to allow use of alternative fuels, the report found:

[34] Fishing Energy Efficiency Review for the Fisheries Research and Development Corporation. Dr D. Sterling. Project No. 2005/239 Final Report - September 2009.

- There were no commercially available technologies identified as having a clear and significant benefit for fishers and therefore strongly recommended for adoption.

On the issue of opportunities for applying innovative solutions and developments which are most likely to produce the best return for the Australian fishing industry, the report found:

- The resources available for fishing businesses to formulate and undertake complex internal change are limited and dependent on business size. Universally very small businesses will need substantial assistance in this task.
- energy utilisation issues for fisheries in many of the key areas. This is a good reference source for a publication to fishers that scopes innovations to potentially reduce energy use. Such a document was produced in house by the FRDC and published in the December edition of FRDC news: FISH.

ii. FRDC Project 2006/229 Development and Implementation of an Energy Audit Process for Australian Fishing Vessels[35]

Key findings from a **comparison of energy audit performance parameters** were:

- Energy audits were completed on a total of seven fishing vessels. Energy audit performance parameters (indicators) for each of these vessels are presented in **Table 18**. The following observations were made in relation to this assembled data:
- The vessels using passive fishing gears (i.e. fish-traps and rock-lobster pots) registered low diesel cost/revenue figures (ranging from 0.09 - 0.17), while the vessels using active fishing gears (i.e. fish trawls and prawn trawls) registered relatively high values (ranging from 0.18-0.34). These results supported the notion that passive gears are generally less energy intensive, and furthermore, that fishing businesses based on passive fishing methods are generally less vulnerable to rising diesel prices.
- The amount of seafood landed per litre of fuel ranged from 0.19 to 1.28kg/L, which at first glance seemed low, and presumably accounts for why fishing is often referred to as an energy intensive food-production method. Interestingly, the production level of the passive gears, in particular the fish-trap, was relatively high compared to the active gears, with only the Victorian fish-trawler (1.28kg/L) surpassing the WA trap-boat (1.07kg/L).
- The catch-revenue obtained per litre of fuel varied considerably across the seven vessels audited ($2.78-11.24/L) and was clearly a function of productivity per unit of fuel, and how much the market was prepared to pay for that type of seafood. The relatively high price paid for rock-lobster ($24-28/kg), over say finfish from SE Australia (about $3.45/kg), clearly influenced this result. To boost business profits in these low-value seafood fisheries, vessels typically must land a greater quantity of fish. This was particularly evident with the SE Australian fish-trawler as it landed about three times as much seafood per unit of fuel compared to the rock-lobster pot vessel; a similar trend was also present across the remaining five vessels.
- The amount of catch landed per unit time was difficult to standardise across the seven vessels due to a difference in the reported fishing-time in each case:
  - WA prawn trawler – hours of darkness
  - SE Qld prawn trawlers – logbook trawl hours
  - WA Fish trawler – trip hours with a deduction for steaming-time to/from the fishing grounds
  - SE Fish trawler – days from port
  - Rock-lobster boat – engine running hours

[35] FRDC Project 2006-229. Development and Implementation of an Energy Audit Process for Australian Fishing Vessels (S.E.S.S.F. Industry Development Subprogram) Prepared by Dr John Wakeford (Australian Maritime College/Uni. Of Tasmania) ISBN 978 1 86295 594 3

- Fish trap boat – days from port

- Based on these differences it was unwise to make comparison between these catch per unit time figures.

Table 18: Energy audit performance parameters for seven Australian fishing vessels (Wakeford, 2006)

Vessel type	Fishery/ fishing region	Fishing period(s)	Diesel cost ($)1 / Revenue ($)	Catch (kg) / Fuel used (L)	Revenue ($) / Fuel used (L)	Catch (kg)/ time (hrs or days*)2
Prawn trawler	Exmouth Gulf Prawn Fishery/NW Australia	Apr-Nov 2007 Apr-Nov 2008	0.18 0.18	0.57 0.78	6.02 8.31	51.3 62.9
Prawn trawler (Ella Mae)	Queensland East Coast Otter Trawl Fishery/SE Qld	Jan-Dec 2006	0.32	0.19	2.78	9.5
Prawn trawler (C-King)	Queensland East Coast Otter Trawl Fishery/SE Qld	Jan-Dec 2006	0.28	0.22	3.19	14.4
Fish trawler	Southern and Eastern Scalefish and Shark Fishery/SE Australia	Jul 07 - Jun 08	0.25	1.28	4.41	1933*
Fish trawler	Pilbara Fish Trawl Interim Managed Fishery/NW Australia	2009	0.34	0.58	3.08	61.6
Rock-lobster pot boat	Western Rock-Lobster Fishery/ Central WA	06/07 07/08	0.09 0.12	0.40 0.44	11.24 10.35	25.5 26.8
Fish trap boat	Pilbara Fish Trap Fishery/ NW Australia	08/09	0.17	1.07	7.07	562*

1 Diesel prices with the Federal government fuel rebate of AUD$0.3814/L deducted.
2 Note that the unit of time varied between vessels and therefore only tentative comparisons can be made. Refer to the accompanying text in the FRDC report 2006/229 for more information

Key lessons learnt and potential refinements from undertaking energy audits on fishing vessels were:

The energy audit performance parameters (indicators) presented were devised to provide a means of monitoring performance within a fishing business over time, as well as permit comparison to be made between businesses. To that end these parameters worked relatively well in this project, although the following modifications were made to facilitate the assemblage or analysis of audit data:

- The 'fuel used/ catch revenue' parameter was altered to 'catch revenue /fuel used' as the latter was more meaningful and easier for industry etc. to interpret.
- 'Catch revenue / fishing day' and 'catch revenue / fuel used' were presented together to ascertain whether efforts to reduce fuel consumption were having a negative or positive impact on catch income.
- The 'Joules of fuel/Joules of protein energy' parameter was omitted from the audits to avoid including a quantity, namely 'Joules of protein energy' that proved to be very difficult to calculate; the difficulty was due primarily to ascertaining what the edible protein portion of a whole fish was, especially once recovery rates and different eating habits were considered.
- A new parameter was introduced, namely 'catch quantity / fuel used', since this new parameter was useful for not only monitoring the impact of fuel saving measures on catch level, but also for making comparison between fishing methods where the same species was targeted, possibly in the same region (e.g. Fish trap boat against Fish trawler in the NW of Australia).
- Two of the quantities in the performance parameters, namely 'catch-revenue' and 'fuel-energy cost', were a function of two other quantities, namely 'unit price' and the 'quantity used, and consequently when the former quantities were combined it was difficult to track what was going on, since a fluctuation in any one of the four quantities could have been responsible for the observed change; further thought needs to be directed towards this matter as the parameter in question was possibly one of the more informative of the set presented in these audit reports.

The report found that **monitoring fuel-energy consumption on fishing vessels was problematic and expensive** for the following reasons:

- fuel-flow meters from Floscan were expensive, costing about AUD$5,000 per unit (imported from USA).

- each combustion engine needed a specific Floscan unit, and most of the fishing vessels had multiple combustion engines (single or dual main-engine plus one or more auxiliaries).
- fuel-flow meters had to be installed by a qualified fitter.
- alterations made to fuel systems had to be reported to the State survey authority and the fishing company's insurer.
- keeping track of where energy was used onboard the vessel proved to be difficult, especially when the engine being monitored had multiple power take-offs or functions, and these additional loads were engaged manually and intermittently recorded.
- Higher level energy audits (i.e. Level 2 and above) necessitate monitoring how much energy is consumed by the fishing vessel for different operational phases, and potentially tracking where this energy is used onboard during each operational phase. Due to the difficulties and expense associated with tracking energy consumption on fishing vessels (explained above), completing higher level audits on this project proved to be a real challenge, and from a project management perspective, both time-consuming and demanding on resources. Future investigators are therefore advised to plan and budget accordingly.
- Presenting energy audit data in a monthly format was difficult to adhere to because fishing trips often extended from one month into the next, making it difficult to apportion the fuel, catch etc. between each month. The solution, if the intention is to analyse trends, is to assemble the data on a scale independent of time, maybe on a trip-by-trip basis over the two-year audit period. However, even this approach struggles to deal with multiple fish unloads/trips against a single refuel, or worse still, a partial re-fuel, since then it is very difficult to ascertain how much fuel was used on the previous trip. For the above reasons, it is highly recommended that fishing companies install fuel consumption meters on at least the main engine (refer to Fig. 45) and ensure accurate records (fuel consumption/hr for each fishing phase, total fuel consumption per trip) are entered by the skipper/engineer in the vessel's logbook for future reference.

iii. FRDC Project 2017/065 Disseminating existing bycatch reduction and fuel efficiency technologies throughout Australia's prawn fisheries[36]

Key findings and recommendations from this report were:

- Check and assess knot orientation to reduce bycatches and improve fuel efficiency.
- Design retroactive modifications to otter boards that facilitate variations from approximately 350° when deploying to the critical 200° when fishing to reduce drag and fuel consumption.

iv. FRDC Project 2013/227 Addressing the urgent need to identify viable refrigerant alternatives for use in the Northern Prawn Fishery[37]

Key findings of this report were:

- The NPF vessel refrigeration application is considered among the most difficult and demanding refrigeration and air conditioning (RAC) industry applications in the Australian economy.
- Much of the fleet's plant is at or beyond its design life and it must move away from the reliance on HCFC-22. The modern fishing fleet is entirely dependent on effective and reliable refrigeration systems and there is no easy 'off-the-shelf' solution for the NPF fleet. Refrigeration engineers and

[36] FRDC project No. 2017/065. Disseminating existing bycatch reduction and fuel efficiency technologies throughout Australia's prawn fisheries. (2019).
[37] FRDC Project No 2013/227. Addressing the urgent need to identify viable refrigerant alternatives for use in the Northern Prawn Fishery

practitioners with specialist knowledge and experience in dealing with this tough and complex application must devise the next generation refrigeration system.

- The only refrigerant that is entirely suitable for delivering the workload required for the exiting NPF vessels is HFC-507A, a refrigerant that will come under regulatory scrutiny within the next decade (or sooner) and face a similar fate as HCFC-22. This leaves fishing fleet owners with one technically viable but possibly uncomfortable option.
- Given the promised removal of the carbon equivalent import levy the authors could not recommend that any vessel owner proceed with paying to replace their system until the timing of that change is confirmed. In the meantime, design and development work on a new system reference design can be undertaken that focuses on refrigeration containment, reduction in refrigerant charge, improved build quality and energy efficiency.
- This task is too complex for one operator to take on board alone and industry needs to act collectively as most of the operators are facing this decision at the same time. The authors are of the opinion that the most efficient way to manage the transition for the fleet is for the industry body to invest in a vessel technical standard and demonstration system. New refrigeration systems can then be ordered with delivery and installation dates scheduled for post the removal of the levy, ensuring reasonable prices are paid for gas. This approach has two major benefits.
- Firstly, it will greatly reduce the cost and time for vessel owners who contract refrigeration services companies to provide new systems to NPF vessels, if they have a reference design with all the important technical decisions made.
- Secondly this process will prove up the capacity and design constraints so that sizing of the critical components for individual vessels will not entail any guess work but will be able to be confirmed by the results of the reference design and its demonstrated performance.
- In the meantime, many in the industry may need to buy time, to ensure continued operation while preparing to install new equipment. Existing HCFC-22 systems will have to be tightened up and inspected for leaks and likely points of leaks eliminated.
- Whenever a vessel is refitted, any HCFC-22 refrigeration that can be reclaimed for reuse should be recovered and stored for sale to others in the fleet that may be retaining HCFC-22 systems for longer.
- All NPF vessels should engage in active preventative maintenance of their refrigeration systems to give them the best chance of operating without major breakdowns and avoid the potential for loss of charge until they can be replaced.

v. FRDC Project 2011/209 Optimising a novel prawn trawl design for minimum drag and maximum eco-efficiency[38]

Key findings and recommendations of this report were:

- A key approach to improving the energy efficiency of trawling and raising the productivity of fishing per litre of fuel consumed is through drag reduction of the trawl system.
- Thee investigators specifically proposed a new trawl concept, named the ''W' trawl'. This is an innovative idea for a more fuel-efficient trawl based on the current understanding of the engineering characteristics of prawn trawl systems. The 'W' trawl has a 'double-tongue' format (tongue in both the headline and footline), and features to enhance the transfer of drag from the body of the trawl to the tongues rather than to the wings.

[38] Project No 2011/209. Optimising a novel prawn trawl design for minimum drag and maximum eco-efficiency, 2014. Balash, C., Australian Maritime College, University of Tasmania, 2014, Optimising a Novel Prawn Trawl Design for Minimum Drag and Maximum Eco-efficiency, Launceston, August. CC BY 3.0

- The developed small prototype 'W' trawl effectively redistributed 64% of netting-drag off the wings and onto the centre tongues, which resulted in drag savings of ~19% for the associated 'W' trawl/ otter board/sled system compared to the traditional trawl/otter-board arrangement in a single trawl or twin rig configuration. Furthermore, based on previously published data, the new system is expected to provide approximately ~11 % drag reduction compared to quad rig. The 'W' trawl system also has benefits over quad rig in regard to the reduced number of cod-end/BRD devices to be installed and maintained.
- The new 'W' trawl technology is a relatively simple and low-cost change for a trawling operation that potentially reduces fuel consumption by 10%-20%. When the potential of the new technology is fully realised (through further gear refinement to improve the catch rate), the trawl's usage will directly reduce production costs of typical Australian prawn fisher by $15,000-20,000 per annum. This equates to about $6M per year for QLD East Coast Fishery.

vi. FRDC Project 2007/200 Alternative Fuels for Fishing Vessels[39]

Key findings and recommendations of this report were:

- Based on an estimate of 270 million litres of fuel being consumed in Australian fisheries, a conservative 5% saving in fuel costs could yield a benefit of the order of $13.5 million dollars per annum. A secondary benefit, yet no less important, is the reduction in greenhouse gas emissions that comes with reducing fuel consumption and the adoption of alternative fuels such as natural gas or biofuels.
- Alternative fuels assessed included low quality distillate (Marine Gas Oil/Marine Diesel Oil, MGO/MDO), natural gas (Liquefied Natural Gas/Compressed Natural Gas, LNG/CNG), liquefied petroleum gas (LPG), biodiesel, fish oil, ethanol, and hydrogen.
- The general conclusion is that **there is no straightforward solution to high fuel costs in terms of alternative fuels**.
- The use of gaseous fuels or volatile liquid fuels could pose safety hazards in the marine context and approval for such use from regulating authorities is likely to be difficult.
- Some net fuel consumption reductions may be achievable with the addition of small quantities of LPG or ethanol to the engine, while the engine still operates primarily on normal diesel fuel.
- Natural gas can be used to replace most of the normal liquid fuel used in a diesel engine. Potentially the purchase price of natural gas is significantly less than normal diesel fuel for the equivalent amount of fuel energy. The main drawbacks of natural gas are that in its compressed form (CNG) the volumes which can be stored on board are low while in its more compact liquid form (LNG) the cost of storage and supply systems is high. The benefits of reduced fuel cost against the cost of implementation of LNG will depend greatly on future fuel pricing, which is difficult to predict. Australia's reserves of natural gas are predicted to outlast our reserves of oil. The acceptance of natural gas by regulating authorities for use on fishing vessels is more likely than for fuels such as LPG or ethanol because there is considerable experience in the use of natural gas in the marine context and thorough guidelines are administered through classification societies.
- Locally produced biodiesel may offer some cost savings, but the pricing of commercially available biodiesel does not offer any cost advantages to off-road users as there is no excise currently applied to biodiesel.
- Fish oil extracted from fish processing waste can be used to make biodiesel, but it is currently more valuable for use as a human nutritional supplement. The available oil represents only 1% of the total fleet fuel usage. There may be up to 3% of the fleet fuel usage available as fish oil in bycatch. However, the use of bycatch for fuel production could be adverse to the management objective of

[39] Project No. 2007/200 Alternative Fuels for Fishing Vessels. Dr Laurie Goldsworthy

reducing bycatch. The potential to use the non-oil components of fish waste to produce diesel engine fuel such as producer gas, whether on-board or ashore, is currently limited by the absence of suitable technology, but this may change in the future.

b) International contemporary research & literature review

i. Carbon in F&A food supply

With the continuing challenge to feed a growing world population there is increasing consumer awareness and consciousness *(Golden 2021, Naylor 2021, Tigchelaar 2021)* that the carbon footprint of food is an important consideration within the assessment of overall ocean and global sustainability. This carbon footprint includes not only the footprint associated with the fishing, even at small scale or subsistence level *(Short 2021)* but the whole supply chain to the consumer. Clearly consumers are looking for information to help make their food and, more specifically, seafood choice more sustainable *(Karwacka 2020, Macreadie & Madin 2015; McKuin 2021)* and researchers are keen to signpost ways for industry to provide that information.

ii. Comprehensive studies

Recent research measuring fuel use globally has led to an upward revision of global fishing estimated CO_2 emissions *(Leotaud 2019)* owing to a recalculation of developing nations' fuel use. This recalibration indicates the sometimes-problematic nature of global-scale analyses. The environmental performance of fisheries and aquaculture systems is similarly the subject of a large and growing body of scientific literature. Recent comprehensive comparisons *(Gephart 2021; Macleod 2021)* indicate the variance in environmental performance between production systems, species, and industries.

iii. Fishery level studies

In the Australian context there is little information allowing the evaluation of carbon footprint of different fisheries. While there may be a temptation to evaluate Australian fisheries on a "like-for-like" basis this literature review found international studies at fishery level *(FAO 2017; Mann 2018; Sandison 2015)* demonstrate that the performance of similar fisheries targeting the same or similar species may diverge widely. In a similar vein, studies focussing on fuel use in fisheries *(Greer et al 2019, Parker 2016)* identify divergent fuel use between fisheries. These are significant research efforts, with the implication that relying on rules of thumb to compare "similar" industries within the Australian context may be problematic.

These studies, in conjunction with the comprehensive studies mentioned above *(Gephart 2021; Macleod 2021)* show that there may be no clear-cut carbon footprint knowledge informing consumer choices between wild-caught and farmed seafood at a global level, as country and industry specific factors can lead to wide variations in carbon footprints between similar seafood products.

iv. Business level studies

Studies of individual aquaculture businesses *(Belettini 2018; Chang 2017)* show that environmental performance of individual businesses producing the same or similar species may diverge widely. The most comprehensive of these assessments employ a life-cycle analysis methodology with the aim of capturing all the contributing components of the business's footprint. Key contributors to the carbon footprint of shrimp, for example, are typically the electricity required for water temperature control, aeration and circulation, and the marine protein and oil, land and water use associated with production of aquaculture feed. Presumably this theme of divergent environmental performance within the wild catch sector would also apply when comparing individual boats within a fishery.

v. Footprint of different forms of transport

Refrigerated seafood can be transported all over the globe, and the resultant supply chain footprint can add considerably to a product's overall carbon footprint. Online tools *(e.g.:detailedcapturecarbontool.seafish.org)* allow comparisons of the carbon footprint per tonne-kilometre of different transport modalities, and thence impact on overall carbon footprint of seafood. These tools make clear that businesses reliant on airborne transport to deliver product to distant markets are intuitively supplying some of the more carbon intensive product. Conversely, shipping containerised frozen product adds relatively small amounts to the overall carbon footprint of seafood.

vi. Refrigerants

Seafood relies on a high integrity cool chain to deliver quality product to consumers. This cool chain begins at the point of capture or harvest and must continue uninterrupted until the point of final sale. Fugitive refrigerant loss is especially significant at boat level, due to often harsh operating conditions *(Brodribb and McCann 2019)* In regard to marine refrigerant use in Australia: "…leak rates have reduced from between 25% and 30% per annum in 2012 to around 15% per annum in 2018". These proportions represent large GHG impacts for fisheries operating with large blast freezing requirements.

vii. Industry's own understanding

A major hurdle for aquaculture producers is gaining an understanding of the embedded carbon footprint attributable to fish feed (see *Cumberledge*, referenced below).

A large part of this footprint is attributable to the farmed components of the feed - land conversion, fertiliser, herbicides, and pesticides that are needed to produce the feed, which are typically soybeans. This land-based food production also gives farmed fish a relatively high footprint where water use is concerned.

The sheer complexity of evaluating all this means that realistically an aquaculture business cannot be expected to perform that analysis, and yet may find it difficult to obtain information from suppliers regarding the carbon footprint of formulated feeds.

viii. Evaluating relative carbon footprint of different businesses within industries with simple tools.

One common theme emerging from industry and business level studies is that there is a clear 80:20 Pareto opportunity for individual businesses to evaluate their own carbon footprint, in that a large part of a business's footprint can be attributed and identified with relatively little effort. In the case where businesses are time poor and labour constrained, following the Pareto principle makes sense.

- The key carbon footprint drivers in wild-caught fisheries are the distances boats travel to fishing grounds, fishing method and catch rates, and refrigerant losses.
- The key carbon footprint drivers in aquaculture businesses, in the Australian context, are electricity (for land-based businesses) and fish feed.

This type of simplified business analysis, using simple tools to accumulate readily available business-specific information, would allow businesses to benchmark themselves against other businesses in an industry. Further advantages for participating businesses or industries might include access to capital, market access or product differentiation opportunities, and support for industry-body level advocacy or marketing.

ix. Once businesses have begun using carbon assessment tools, then what?

Having begun using business carbon assessment tools, what can fishers do with that knowledge? Benchmarking against other businesses may demonstrate areas of business underperformance.

A high fuel use intensity could signal the need to conduct a fuel use audit and investigate alternatives. Examples in literature *(Johnson 2014, Kemp 2021)* indicate that considerable costs savings, in addition to carbon footprint reduction, are achievable. Similar audit programs are in place for land-based businesses - for example Energy Savers Plus Programs targeting energy savings for Queensland aquaculture farms.

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