Final report

Carbon footprint and reduction options for Harvest Road Group operations

Public Report

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Abstract

This project developed a baseline carbon footprint and strategy to reduce emissions and store carbon towards a carbon neutral target for the Harvest Road Group (HRG) supply chain and undertook market research to engage consumers.

The farm-gate carbon footprint, reported as an emission intensity, was 12.1 kg CO_2-e kg LW^{-1} for the two years to FY20. Reported for boxed beef ready for wholesale, impacts were 27.4 kg CO_2-e kg boxed $beef^{-1}$. Over 90% of emissions arose from third-party suppliers, with enteric methane from cattle being the largest emission source. Net emission reduction strategies for implementation to 2030 including improved herd management, use of novel feed supplements and carbon storage in vegetation and soil.

Market research found 1 in 4 consumers indicated a willingness to pay 15% more for carbon neutral beef, reducing to 1 in 5 when the price premium were set at 30%, indicating a proportion of consumers may be willing to pay for improved environmental performance, which will be vital for driving change.

Achieving the carbon neutral goal requires a whole-of-supply-chain approach, engaging all stakeholders from producers to consumers in a major effort to implement new practices, increasing environmental performance and delivering premium WA beef to the market.

Executive summary

Background

This report provides a supply chain emission intensity, market review insights and net emission reduction plan for the HRG supply chain. HRG is Western Australia's largest beef processor, currently operating an extensive supply chain that includes pastoral properties (stations), backgrounding, finishing, and a meat processing plant (Harvey Beef), all located in Western Australia. HRG has established a goal for positive climate action within the organisation and the supply chain, are working for carbon neutrality ahead of industry targets, and supports the industry to achieve their CN30 goal. This report provides a supply chain emission intensity, market review insights and a net emission reduction plan to help guide the changes required to achieve HRG's carbon neutral targets.

Objectives

The specific objectives of this project are:

- Determine the supply chain carbon footprint and opportunities to develop carbon neutral beef production.
- Identify demand driven carbon neutral product opportunities via a comprehensive research study and stakeholder interviews.
- The outputs of the project will include a carbon footprint and net emissions reduction strategy report, and a market insights report (from market research).

Methodology

The analysis was completed in four stages. An emission baseline was developed for the business covering scope 1 and 2 emissions, followed by an analysis covering scope 3 emissions, including livestock purchased for grain finishing and meat processing for the two years including FY 19 and FY 20. Third, a market review was undertaken to investigate consumer attitudes to carbon neutral beef. Fourth, a net emission reduction plan was established for supply chain (scope 3) emissions.

Greenhouse gas (GHG) emissions were modelled using established methods consistent with the National Inventory Report (NIR) (Commonwealth of Australia 2021) for agricultural emissions, and consistent with the National Greenhouse Gas Accounts (NGA) for energy related emission sources. Livestock performance data were collected from company records to determine livestock emissions. Scope 3 emissions from purchased livestock were modelled using data from meat processing regarding the weight and age at processing, and region where cattle were bred. WA herd data from ABARES were used to determine herd performance in the major production regions.

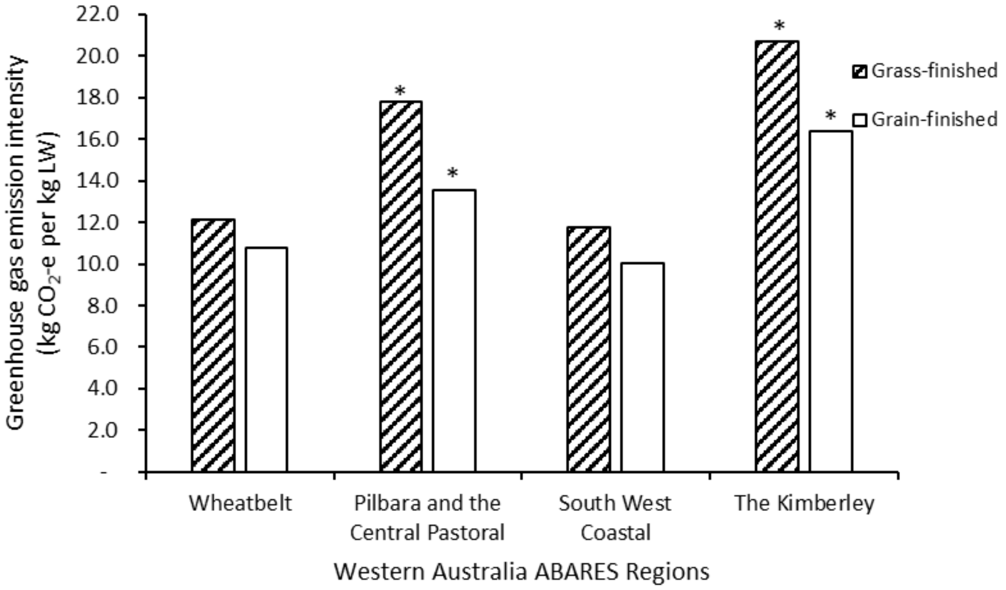
Results/key findings

Supply chain carbon footprint

The mean emission intensity for the supply chain pre-processing was 12.1 kg CO_2-e kg LW^{-1} purchased by Harvey Beef. The mean emission intensity for grass-finished beef was 13.3 kg CO_2-e kg LW^{-1}, with a range of 11.8 to 20.7 kg CO_2-e kg LW^{-1} depending on the source region (see Figure 1), noting that the supply of finished cattle from northern regions was small and may not be representative. Mean emission intensity for grain-finished beef was 10.7 kg CO_2-e kg LW^{-1} and ranged from 10.0 to 16.4 kg CO_2-e kg LW^{-1} depending on region (Figure 1). Mean emission intensity for grain finished beef was 20% lower than the mean emission intensity of grass-finished cattle, principally because lifetime ADG and processing weights were higher than for grass finished cattle.

The emission profile was dominated by enteric methane (av. 81%) followed by nitrous oxide (av. 10%) and carbon dioxide (av. 9%). Emissions from grass-finished cattle dominated the emission profile. On average, enteric methane from grass-finished cattle and grain-finished cattle prior to feedlot entry contributed 78% of emissions prior to processing, whilst enteric methane from grain-finished cattle while cattle were being finished contributed 3% of pre-processing emissions.

Figure 1. GHG emissions intensity (kg CO2-e kg LW sold^{-1}) for grass-finished and grain-finished beef across the WA ABARES breeder regions



** Results for the Pilbara and the Central Pastoral and the Kimberley were not representative of a stable herd due to large numbers of other sales outside the Harvey Beef supply chain. These results should be interpreted with caution.*

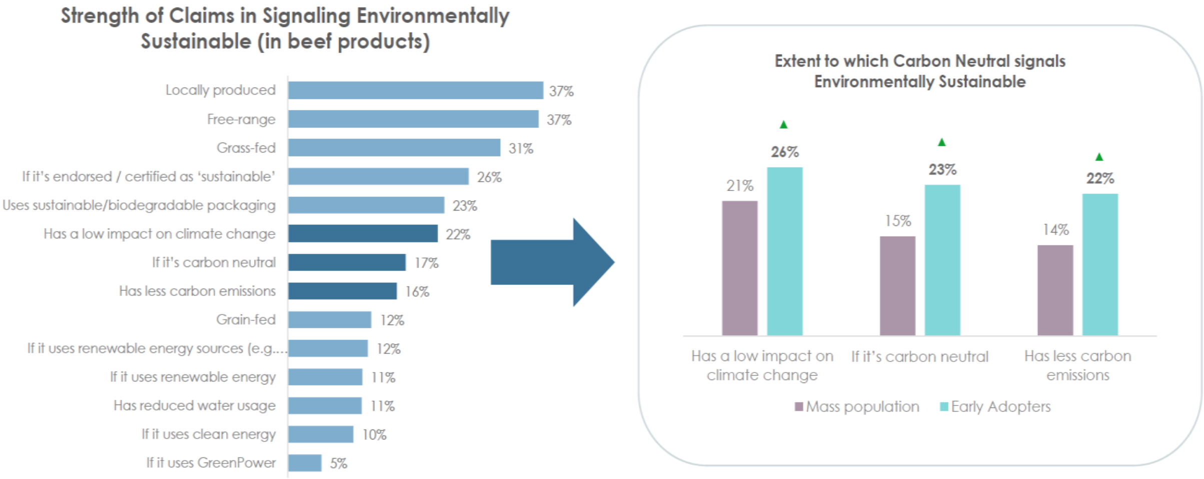
After accounting for meat processing, the full supply chain emission intensity up to the point in which beef is ready for transport from the meat processing plant was 27.4 kg CO_2-e kg boxed beef^{-1}. Of this, 2.8% of emissions were from meat processing. The emission intensity associated with meat processing

(processing impacts only, not including upstream beef production) was found to be 0.59 kg CO_2-e kg HSCW^{-1}.

Market Review

A comprehensive research study was undertaken by Nature Pty Ltd and The Lab Insight and Strategy Pty Ltd to understand key insights and opportunities to inform future carbon neutral product development. The study revealed that while general understanding of environmental sustainability is high (69%), understanding of carbon neutrality is lower (52%) especially when regarding the meat industry (23%). Consumers were found to be more drawn to sustainability solutions that have consumer-facing impacts such as reduced plastic packaging or the utilization of renewable energy, with indicators such as "locally produced" and "free-range" being the strongest identified "sustainability" indicators (see Figure 2). This highlights the need for further public education on the purpose and role of carbon neutral beef in achieving sustainability goals.

Figure 1. Responses to the question "Thinking about sustainability in the context of buying beef products, what signals to you that a beef product is environmentally sustainable?"



Consumers have mixed reactions towards the pricing of carbon neutral beef, with 26% responding they will always choose the sustainable and eco-friendly option. This market segment of 'Early Adopters' (approximately 1 in 4 consumers) indicated willingness to pay 15% more for a carbon neutral beef option, reducing to 1 in 5 consumers when the price premium is set at 30%. However, a further 57% of survey respondents expressing that it was "just too expensive" to do the right thing for the environment all the time.

The key insights discovered during the qualitative study were:

- People care deeply about sustainability and are changing their behaviours to be more eco-conscious.
- Carbon neutrality is not well understood. It is a new concept that has little presence in the market.
- Carbon neutrality is not something that people expect from brands or prioritise right now.

- Consumers are the driving force behind sustainability action and brands are currently the driving force behind carbon neutrality.
- In the transition to carbon neutrality, communication and messaging needs to be watertight and consistent.

Net emission reduction pathways – supply chain

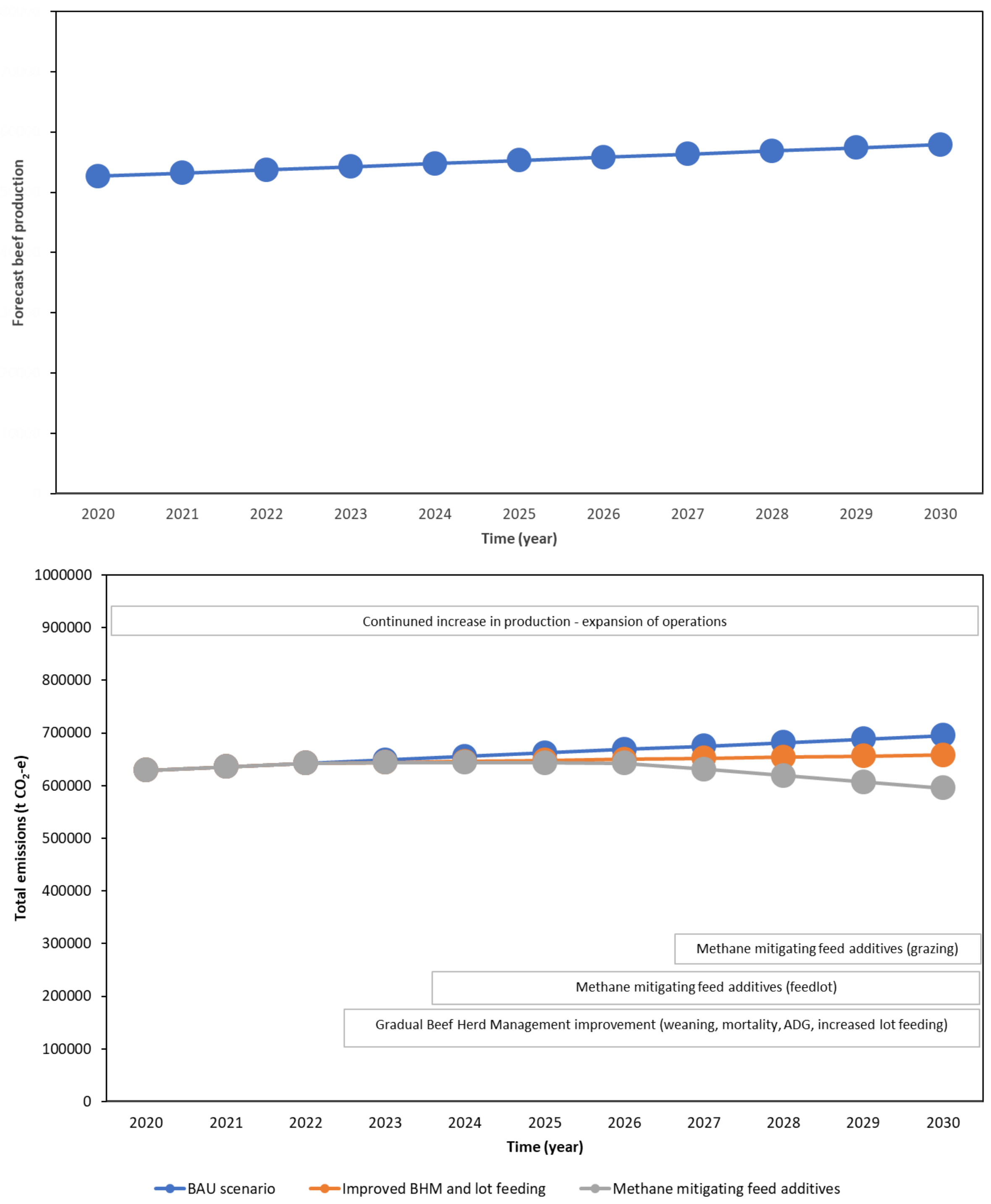
To identify pathways towards carbon neutral by 2030 for the supply chain, a total of 53 emission reduction options were screened for applicability across supply chain operations (including grazing, feedlot and meat processing for emission mitigation, as well as soil and vegetation carbon sequestration). The screened emission reduction and carbon sequestration options were utilised to formulate pathways to carbon neutral by 2030 for the supply chain. Due to the additional complexities of geographical spread and distribution variabilities across the supply chain, additional modelling was undertaken to determine the impacts of the various mitigation scenarios when combined with distribution changes. Mitigations were then grouped into three pathways (Table 1).

Table 1. Emission mitigation pathways for the supply chain

Strategy	**Description**
Pathway 1 (P1)	BAU emissions approach. Expected expansion in beef supply based on industry estimates.
Pathway 2 (P2)	Beef herd management improvements undertaken (herd improvement via better weaning rates, higher turnoff weight, faster turnoff, improved mortality). Expansion of grain feeding.
Pathway 3 (P3)	P2 + methane mitigating feed additives and supplements across the supply chain at different intervals (grain-feeding and grazing).

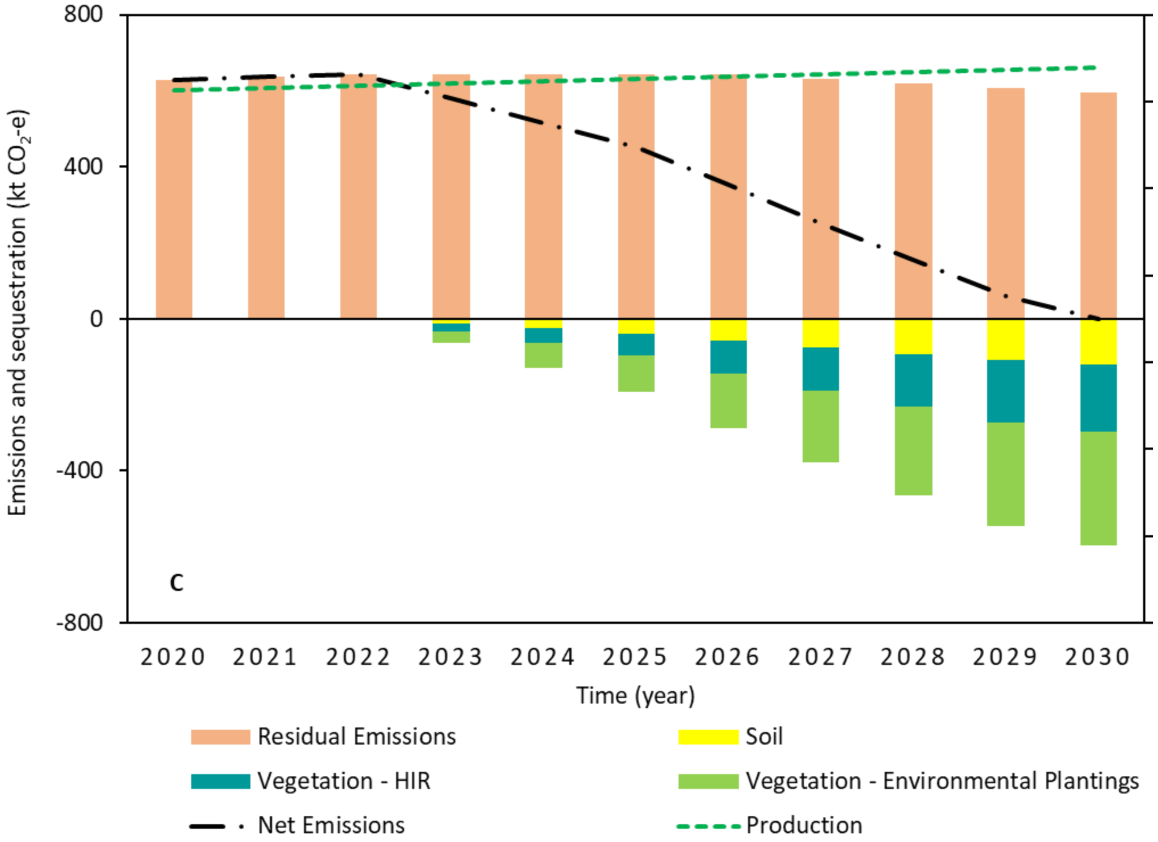
Then emissions data is scaled to a turnoff of 100,000 head per year. The increase in production through the decade and the emissions profiles of the three pathways are displayed in Figure 3. The three scenarios display the relative impacts of various activities when compared to a baseline “no action” pathway. Pathway 2 provides a reduction of 5.3% from the baseline and pathway 3 provides a 14.3% reduction.

Figure 3. Top: Estimated production increases (%) forecast through to 2030. Bottom: The emission mitigation pathways for the supply chain to 2030.



Pathway 3 is defined as the optimal pathway to follow for the supply chain due to the increased mitigation potential and therefore reduced requirements on sequestration. As this approach does not achieve carbon neutrality, sequestration from soil and vegetation is required to achieve the goal and is displayed in Figure 4.

Figure 4. Pathway 3: Emission mitigation and sequestration required to achieve carbon neutrality by 2030



Due to the variability in soil and vegetation potential across the supply chain, further investigation is required to develop a sequestration strategy tailored to the supply chain. This study considered ERF methodologies only for vegetation carbon sequestration. It was identified that the ERF has limitations in relation to eligibility of land and carbon storage quantification that can be attributed to landholders. As a result, new strategies are required to quantify vegetation in areas that don't fit with ERF methods. Soil carbon shows promise, however is currently very expensive, particularly when measuring small change over large areas such as in pastoral zones. Lower-cost measurement will be critical for assessing soil carbon change moving forward.

Key Findings

This study presents the first large scale baselining and emission reduction plan for a beef supply chain in Australia, to the author's knowledge. The study provided a clear view of the emissions profiles and emission reduction opportunities of a large-scale supply chain in Western Australia, with relevance to the broader Australian beef industry; particularly relating to current market insights and the program of work required through research, extension and development to achieve current industry emissions goals.

- Beef herd management improvements, such as improved weaning and growth rates, reduced mortality, and expansion of grain feeding are expected to achieve ongoing, incremental improvements in the emissions intensity profile of the supply chain, in this case leading to an improvement of 5.3% to overall supply chain emissions intensity. Opportunities are greatest for the northern industry, where cattle performance is more constrained and the opportunities for improvement are greater. This will be necessary to reduce emissions, particularly if the industry is to expand throughput by drawing more cattle from the north of the state.
- Methane mitigating feed additives have the potential to deliver significant methane emission reductions at various points of the supply chain, such as during grain finishing. Feed additives were assumed to provide benefits within feeding facilities from 2024 and to grazing operations from 2027. Supply chain emissions mitigation from feed additives was forecast to improve incrementally throughout the decade, achieving a 9% improvement in emissions intensity for the supply chain by 2030. Together with beef herd management, combined emission mitigations were forecast to be 14.3% for the supply chain emissions intensity by 2030.
- Considering the central role of methane and the challenges in substantially reducing methane in the supply chain to 2030, there would be merit in further examining what is required to assess and potentially accredit so called “Climate Neutral” supply chains, which may apply different metrics for assessing the impact of methane.
- This study identified that carbon neutrality would require a significant amount of sequestration in soil and vegetation. Significant effort will need to be invested in establishing the practices and measurement approaches needed to achieve these outcomes and measure the impact across the supply chain. Specifically:
    - Lower-cost measurement is a critical need for assessing soil carbon change. Current ERF soil carbon projects are very expensive, and costs are greatest when measuring small change over large areas such as in pastoral zones. This is a critical gap for the beef industry.
    - Vegetation ERF methods are suited to large projects. In a supply chain context, many small projects are required to quantify vegetation carbon sequestration. Costs are anticipated to be a barrier to widespread adoption. Other systems with lower compliance costs are required that can reliably quantify vegetation carbon sequestration in small areas on large numbers of farms.
    - New strategies are required to quantify vegetation sequestration in areas that currently don’t fit within the ERF methods. For example, sequestration occurring in forest that can’t be cleared for regulatory reasons can’t be included in the ERF, but there may be other mechanisms that can enable beef supply chains to quantify and claim the sequestration from these sources.

Market engagement:

- The market study revealed that consumers have a general understanding of environmental sustainability, however understanding of carbon neutrality in relation to the beef industry is lower. A strong market of environmentally-conscious ‘Early Adopters’ was identified, with a proportion of the public willing to pay a price premium for carbon neutral beef products. It was discovered that people care deeply about sustainability and are changing their behaviours to be more eco-conscious, however carbon neutrality is not currently well understood and has limited market presence. As a result, actions to deliver watertight and consistent communication and messaging to consumers and industry are required, including at brand level.

Supply chain engagement:

- This project revealed that the majority of emissions and the greatest opportunities to reduce emissions or sequester carbon arise at the farm scale. However, engagement with customers and consumers seeking better environmental credentials primarily happens amongst brand owners and retailers. Improving and communicating environmental credentials requires an integrated, whole-of-supply-chain approach with high engagement with producers through to consumers and Government. To bring transformative change, two key needs have emerged:
    - Firstly, systems will need to be implemented to enable transfer of information around the carbon credentials of livestock and beef throughout the supply chain. This needs to be done in a robust and auditable way, and cost sharing will be required across the supply chain.
    - Secondly, cost minimisation and a mechanism to fund carbon neutrality is needed throughout the supply chain. Consumers and Government will be a critical stakeholders to engage to build a suitable model to fund carbon neutral beef into the future.

The above findings highlight the need to develop an adoption program in the supply chain with a mid to long term view (at least to 2030) to address the many and complex needs that emerge in bringing transformational change across the whole supply chain.

Benefits to industry

For the industry CN30 goal to be achieved, it must be put into practice in commercial supply chains at scale. This is the first analysis of its kind, to comprehensively assess realistic emission reduction and carbon storage potential, while increasing beef production. Results were scaled to a 100,000 head turnoff to improve relatability to other supply chains. While the results and pathways reflect WA production conditions, these were not dissimilar to conditions in south-eastern Australia, and the mitigations were also generally applicable, though in some regions other options would also be available. The study showed that concerted effort across the whole supply chain will be required to achieve CN30. Other supply chains, including retailers, larger grain finishing businesses and meat processing plants could replicate this process to understand emissions and develop meaningful pathways to bring about change. While the context here has focused on carbon neutrality per kilogram of product, business net zero targets that cover only scope 1 and 2 emission sources are also appropriate as corporate goals.

Further research and recommendations

As a result of the identified pathways to carbon neutral, an action list was developed to target priority actions for the supply chain, including actions already being taken as a part of this investigation. These are listed in Table 2.

Table 2. Priority actions to achieve carbon neutrality by 2030 for the supply chain

Action	Timeframe
Baseline carbon footprint and establish emission reduction and carbon storage options with suppliers and be able to report this into market claims.	2022-2030. Intensive focus 2022-2024.
Provide demonstration and extension programs to producers to enable best practice uptake, including using HRG operations.	Launch 2022. Deliver programs from 2022-2030. Intensive focus 2022-2024.
Establish a cost-effective program for suppliers and Harvey Beef for carbon neutral beef.	2022-2030.
Undertake gaps analysis and create a feedback loop to research.	Intensive focus 2022-2023. Annual feedback loop 2022-2030.
Implement supply chain wide enteric methane mitigation in feedlots via supplement usage.	2023-2027
Implement mitigation strategies via improved herd management in northern regions.	2022-2030
Develop and implement soil carbon sequestration projects at scale throughout the supply chain.	2022 onwards
Implement vegetation projects – HIR and tree planting at scale throughout the supply chain .	Pilot and demonstrate from 2022. Implement broadly from 2025-26.
Implement enteric methane mitigation strategies in grazing herd at scale throughout the supply chain via supplement usage.	2028-30

Further programs are required to deliver carbon neutrality by 2030. The scale of HRG and their reach across the beef supply chain in WA provides a unique opportunity to lead a noticeable improvement in the sustainable and profitable production of Australian beef.

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1. Background

Society wide, there has been increasing concern over greenhouse gas (GHG) emissions and their contribution to global warming. Many companies, governments and industries are working to establish targets and develop strategies to reduce GHG emissions. The Australian red meat and livestock industry, supported by Meat & Livestock Australia (MLA), has set a goal for the red meat industry to be carbon neutral by 2030 (CN30). Individual companies are now working to determine the emission profile for their operations and to develop implementable plans to reduce emissions and achieve carbon neutrality within their supply chains.

Western Australia (WA) produces some 5% of Australia's beef (ABS 2020). Beef production in WA is distinctly separated into a northern herd and a southern herd. The northern WA beef industry is characterised by extensive pastoral stations with relatively low input production. These systems utilise native or naturalised grasslands and flexible management adapted to high climate variability, where frequent droughts limit pasture productivity and cattle performance. *Bos indicus* cattle are commonly produced in this region for the live export market. Southern WA is characterised by high input systems which are more productive than northern WA, with higher weaning rates, growth rates and more beef produced per hectare. Cattle produced in northern WA that are not sold for the live export market must be transported great distances for processing, or for backgrounding and finishing in southern WA before being processed. Unlike the Queensland beef supply chain where large numbers of cattle move from north to south for backgrounding and finishing, there are limited numbers of cattle moving south in WA and few feedlots have been established to feed northern cattle.

Harvest Road Group (HRG) currently operates an extensive supply chain that includes HRG pastoral stations, backgrounding & grain finishing, and a meat processing plant (Harvey Beef) located in Harvey, approximately 150km south of Perth. Harvey Beef is the largest beef processor in WA, and principally sources cattle from southern WA, and a smaller proportion of cattle from northern WA. Cattle from the Northern stations are trucked south to a feeding program, then onward to Harvey Beef for processing, making HRG one of the few vertically integrated, north-south beef producers in WA.

HRG has established a goal for positive climate action within the organisation and the wider WA beef industry. HRG are working towards carbon neutrality ahead of industry targets and supports the industry to achieve their CN30 goal. To support this goal, the present study aims to determine the supply chain carbon footprint, complete a market assessment to determine community attitudes towards carbon branding and develop a net emission reduction strategy.

2. Objectives

The specific objectives of this project are:

- Determine the supply chain carbon footprint and opportunities to develop carbon neutral beef production
- Identify demand driven carbon neutral product opportunities via a comprehensive research study and stakeholder interviews
- The outputs of the project will include a carbon footprint and net emissions reduction strategy report, and a market insights report (from market research).

3. Methodology

3.1 Project scope – Baseline

This project completed a calving to meat processor gate carbon footprint (scope 1, 2 and 3 emissions).

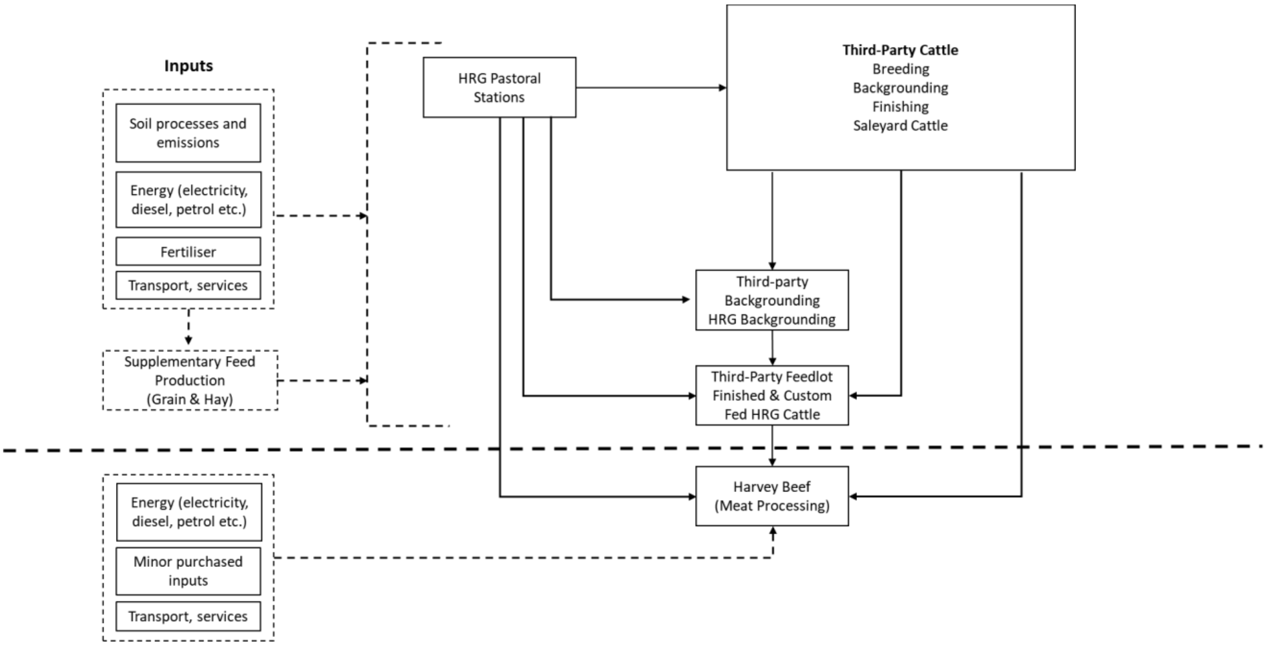
Emission estimates were determined using the AR5 IPCC global warming potential characterisation factors (GWPs) (Myhre *et al.* 2013) (Table 3). Emissions are reported as carbon dioxide equivalents (CO_2-e). This unit is used to compare emissions from different GHGs based on their global warming potential (GWP) over a specified period, typically 100 years (GWP_{100}). Greenhouse gas emissions and carbon storage resulting from land use, direct land-use change, and land-use change were not included in the assessment, due to difficulties in attributing these emissions to cattle compared to other land uses such as sheep or cropping in the third-party cattle supply chain. Gross emissions from the WA GHG footprint were reported for context.

Table 3. Global warming potential (GWP_{100}) values relative to CO_2 (Myhre et al. 2013)

Greenhouse Gas	Chemical Formula	Fifth Assessment Report (AR5)
Carbon Dioxide	CO_2	1
Methane	CH_4	28
Nitrous Oxide	N_2O	265

The production system included cattle from across a varied supply chain that were processed at the Harvey Beef abattoir. To improve the interpretation of these results in relation to other supply chains, the results scaled to 100,000 head of cattle turned off annually. Harvey Beef purchases a small proportion of steers from the dairy industry. For the purposes of this study, the emissions from these cattle were assumed to be equivalent to emissions from the beef herd supply chain, which was a conservative assumption. Further detail around the emissions from this segment of the supply chain may be investigated at a later point. A general description of the supply chain is provided in Figure 5.

Figure 5. Harvest Road Group cattle supply chain



For reporting emissions intensity, reference units were used that aligned with different stages of the supply chain. For beef production emissions at farm scale, impacts were reported in kg CO_2-e kg LW^{-1} purchased by Harvey Beef. For meat produced at the processing plant, impacts were reported per kg CO_2-e kg boxed $beef^{-1}$. For comparison with benchmarking data, impacts from meat processing (not including upstream beef production) were also reported per kg CO_2-e kg $HSCW^{-1}$.

3.2 Inventory data - third party cattle suppliers

The majority of cattle processed at Harvey Beef are sourced from third-party cattle producers. Cattle may be directly purchased from cattle producers or saleyards. To determine emissions, a spatially defined herd inventory for the Harvey Beef supply chain was developed utilising the Harvey Beef processing data, the ABARES survey data and livestock productivity parameters collected from producer focus groups and literature sources to enable a full cattle herd profile to be established.

Herd data sourced from Harvey Beef

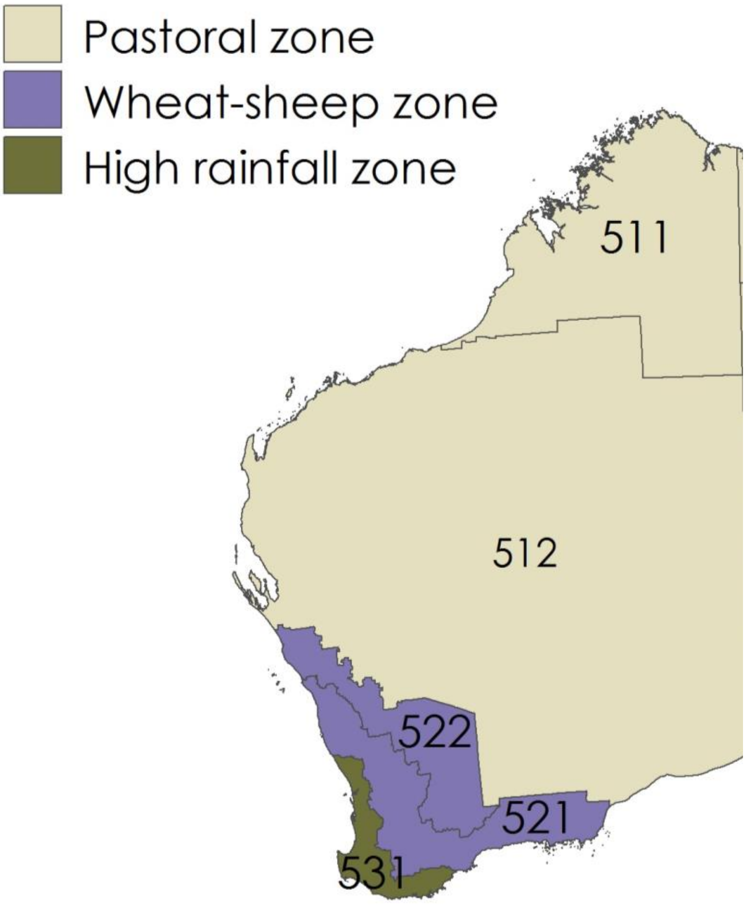
Processor data were categorised by class, sex, feeding type (grain vs grass) and breeder region. Live weight for each cattle class was determined from fat depth, carcase weight and sex (Meat & Livestock Australia 2017). Cattle processing age was determined from carcase characteristics and the difference between processing date and the estimated mean calving date for each region.

ABARES herd and farm services data

ABARES regional data for “All beef industries combined” (ABARES 2021) were utilised principally to structure the supply regions and provide key input data on herd structure and purchased inputs. Western Australia's ABARES regions are divided into the Central and South Wheatbelt (521), North and East Wheatbelt (522), Pilbara and the Central Pastoral (512), South West Coastal (531) and the Kimberley (511) (Figure 6).

Data were sourced from the most recent two-year period available in the ABARES dataset. There were no data available for North and East Wheatbelt, so for simplicity the Central and South Wheat and the North and East Wheatbelt ABARES regions were combined. From here on, these two regions are referred to as the Wheatbelt.

Figure 6. Map of Western Australia showing ABARES regions



Key production parameters used from ABARES in constructing the HRG WA herd production model included weaning percentage, bull inclusion rate and mortality.

All farm purchased data were also sourced from ABARES. Within the ABARES dataset, farming sub-systems were subdivided, and inputs associated with crop production and sheep were excluded. Input data were scaled to the appropriate herd size for the Harvey Beef supply based on dry sheep equivalent (DSE) units. Key data parameters include farm fuel use, feed inputs, fertiliser, services, transport of farm inputs, and cattle transport throughout the supply chain.

Cattle processed at Harvey Beef were scaled to reflect a 100,000 head throughput, and included cattle from across the state. It was recognised that the herd supplying cattle to Harvey Beef is not completely reflective of the actual herd in each of the state regions, which would in practice supply cattle to multiple meat processing plants and the live export market. In particular, the herd providing processing cattle from the Pilbara and Kimberley are likely to be atypical of these regions, because most young cattle in these regions are sold to live export and this wasn't reflected in the modelled herd. Further work is required to comprehensively understand the profile and the emissions from these herds if they were to be reflective of the region, rather than HRG supply only.

Table 4. Cattle production parameters of grass-finished beef and grain-finished beef from Harvey Beef abattoir across the WA ABARES regions

	Grass- Finished				**Grain - Finished**			
Key Production Parameters	**Wheatbelt**	**Pilbara and the Central Pastoral***	**South West Coastal**	**Kimberley***	**Wheatbelt**	**Pilbara and the Central Pastoral***	**South West Coastal**	**Kimberley***
Weaning per cent (%)	87%	69%	92%	61%	87%	69%	92%	61%
Breeder culling rate (%)	14%	20%	14%	20%	14%	20%	14%	20%
Mortality rate (%)	1.8%	4.6%	1.3%	4.1%	1.8%	4.6%	1.3%	4.1%
Weaning age (days)	213	213	213	213	213	213	213	213
Heifer lifetime ADG (kg/day)	0.8	0.5	0.9	0.4	0.9	0.7	1.1	0.5
Steer lifetime ADG (kg/day)	1.0	0.7	0.9	0.5	1.0	0.8	1.3	0.7

* Herd production parameters in these regions were based on relatively smaller numbers of processing cattle and are unlikely to be fully reflective of production in these regions.

Harvest Road Group custom fed cattle data

Data from the custom fed feeding program were analysed to provide mean days on feed (DOF) in the feeding facility, to model the grain-finished herd. The mean finished weights from the custom fed cattle was substantially higher than the mean finished weight of grain-finished cattle from the Harvey Beef abattoir data. This suggested that some cattle classified as 'grain-finished' included cattle that were supplemented or paddock finished on grain, rather than in dedicated feedlots. Considering this, "grain-finished" in this study is not fully comparable to commercial lot-fed cattle and this needs to be considered when interpreting the results and comparing with literature values.

3.3 Inventory data

3.3.1 Production Data

Detailed production data, livestock inventories, and input data such as purchased feed, fertiliser, fuel and services for the HRG operation were combined and analysed as a single herd. Key metrics such as breeding cattle and processing cattle weights were utilised, as recommended in the Emissions Reduction Fund (ERF) Beef Cattle Herd Management (BHM) method. Where livestock were purchased, livestock related emissions prior to entering the system were considered pre-farm emissions (i.e. scope 3) and were determined using the relevant herd parameters from the ABARES dataset combined with the Harvey Beef data. A two year baseline period was selected (FY 2019 & FY 2020) to minimise fluctuations caused by annual changes in herd management and seasonal variation – which can have a large influence on livestock production, livestock movements, performance and emissions intensity.

Services emissions from grain finishing facilities were allocated to the herd based on head throughput for the period of available data. Cattle performance and feedlot inputs were estimated based on data from Wiedemann et al. (2017) and Wiedemann & Longworth (2021).

3.3.2 Meat processing plant data

Meat processing impacts were determined through inventory data for the meat processing plant, including energy use, waste stream processes and production data per unit of output. A meat processing plant model was utilised to determine the emissions impacts per unit of beef. This included determining the allocations to other products at point of processing such as hides, edible offal and rendering products in addition to boxed beef. An estimated dressing percentage was determined based on the proportion of cattle from different classes and standard industry dressing percentage estimates (Meat & Livestock Australia, 2017).

The general approach to modelling the flow of products, and impacts from meat processing, was described in Wiedemann & Yan (2014).

3.4 Handling co-production

Within a typical beef supply chain, various products are often co-produced on the same farm, such as beef, sheep and cereals. Inputs associated with cropping were first deducted based on the area of crop land sown annually, with remaining inputs associated with sheep and cattle then divided based on the stocking rate of each, expressed per DSE. Manure nutrients from the grazing herd were assumed to return directly to pasture and were therefore considered a biological feedback loop without the need for allocation. Feedlot manure was treated as residuals, following guidance for the environmental performance of large ruminant supply chains (FAO 2016). Within the cattle production system, there was no differentiation between live weight from young cattle or from cull breeding animals.

During meat processing, meat, edible offal, tallow, raw hides, blood products and blood meal are co-generated. All edible outputs (i.e. boxed beef and edible offal) was treated as an equivalent product, resulting in no need for allocation between these products. Allocation between meat and other co-products at the point of meat processing was handled using economic allocation (FAO 2016).

3.5 Greenhouse gas (GHG) estimation

GHG emissions were modelled by region for livestock (enteric methane and manure emissions) and for purchased inputs (fuel, electricity, feed, purchased cattle etc.) throughout the supply chain. This study conducted livestock GHG emission modelling according to life cycle assessment (LCA) practices published in the peer-reviewed literature for feedlots (Wiedemann et al. 2017) and grazing systems (Wiedemann, McGahan, Murphy, and Yan 2015). The methods are not inconsistent with the international guidance for conducting livestock LCA (FAO 2016). Feed intake, enteric methane and manure emissions were determined using methods consistent with the NIR (Commonwealth of Australia 2021) for the baseline assessment. Inventory data related to dietary crude protein and dry matter digestibility, used in estimation of manure emissions, used regional assumptions from the NIR. With respect to feedlot enteric methane, the NIR uses the method of Moe & Tyrell (1973) which was developed for dairy cattle in the USA. This method has not been validated with Australian research, and has resulted in higher emission estimates than Australian studies (McGinn et al. 2008; de Almeida et al. 2021). This method was used in the baseline assessment. However, considering the goal of the present study was to determine emissions out to 2030, an updated factor was used to better reflect likely emissions from feedlots. The factor of 13.6 g CH_4 per kg DMI from IPCC 2019 (Gavrilova et al. 2019) was applied.

3.5.1 Methane Accounting

It is important to note that changes to IPCC GWP100 values, including methane, have occurred historically, and are expected to occur in the future as the science improves. Likewise, there are potential alternative methods to model and quantify the impact of methane. Debate is ongoing regarding the GWP100 approach, with concern expressed from some proponents that this approach overstates the effect of methane emissions from stable herds of livestock. Alternative methods such as the GWP* have been proposed, and it may be possible to re-cast emission reduction strategies with these alternative approaches in the future, shifting towards a 'climate neutral' target rather than carbon neutral. One central problem is that these alternative approaches typically compare emissions to a 20-year historic baseline, which is a very different basis to most annual carbon accounting. They are also sensitive to changes in total methane, with increased methane emissions resulting in grossly higher reportable warming impacts. This is challenging for individual enterprises or supply chains because expansion plans may lead to higher emissions of methane at least over short term horizons.

The present report uses the accepted rules of carbon accounting enshrined in global accounting requirements. However, overcoming limitations around methane accounting at the supply chain and enterprise level should be an industry priority and as this project moves to the next stage, reviewing methane accounting constructs and targets should be an ongoing consideration.

3.6 Data limitations

The study relied on data from several different datasets to construct the herd model from which GHG predictions were made. A degree of caution should be applied in interpreting the results. The process of calibrating the model to deliver known output, in terms of the total volume of cattle processed at Harvey Beef and the characteristics of the cattle processed, ensured productivity was not grossly over- or under-predicted, but the method used to predict the size of the breeding herd producing processing cattle, and the age at processing, contained a degree of uncertainty. Moreover, the method applied did not allow reasonable estimate of the structure of herds that had a large number of sales to other markets such as live export. For this reason, the results for the northern regions (Pilbara and the

Kimberley) were less reliable, though these also contributed a much smaller proportion of the cattle and were therefore less influential in the model.

Some activity data, methods and emission factors used in the National Inventory Report (NIR) may currently under- or overestimate emissions from some sources. The Moe and Tyrell (1979) method, used in the NIR for calculating enteric methane in feedlot cattle, does not account for dietary oil which is commonly fed and is known to reduce enteric methane. Alternative methods for predicting feedlot enteric methane such as the IPCC indicate lower emissions than predicted using Moe & Tyrell and Australian research has also shown emissions to be lower from feedlot cattle. Further Australian research is underway to establish better prediction methods for Australian feedlot cattle.

3.7 Carbon neutral pathways

3.7.1 Screening of emission mitigation and sequestration options

A screening assessment of potential options to reduce net emissions was conducted. This screening exercise was conducted for the supply chain to achieve carbon neutrality by 2030.

The options were prioritised towards those with the greatest potential to reduce net emissions in the short term and at scale. The screening criteria were as follows:

- emission source targeted
- technical mitigation potential and viability
- economic viability
- productivity and co-benefits
- Emission Reduction Fund (ERF) potential
- availability and timelines for implementation
- further research and development required.

The net emissions reduction options were segmented by grazing, feedlot, energy, soil sequestration and vegetation sequestration.

Vegetation sequestration options were limited to ERF methods within the scope of this study. This is potentially a limiting factor, as ERF methods are limited in scope. While further opportunities exist to store carbon in agricultural landscapes, it is difficult to formally account for these impacts in the marketplace without an offset method or equivalent, robust method. Further research is needed in this space to expand the options available for industry to store carbon, particularly in ways that complement rather than compete with production goals. Methods and systems are also needed that enable smaller producers to offset emissions at reasonable cost for compliance, and this is a key, ongoing need. In this context, the term ‘insetting’ is useful; referring to the practice of generating sequestration within the boundaries of their business, to offset business emissions. While these needs are important for implementation, they were beyond the scope of the project to address. .

The screening outcomes are displayed in the results section of this report.

3.7.2 Pathways to carbon neutral: supply chain

Future production and emissions pathways were developed through to 2030 for the supply chain. Emissions and production modelling was undertaken to estimate the potential outcomes of various activities. Considerations were given to the scale and diversity of the supply chain, across a wide area of Western Australia,

Three pathways were developed for the supply chain to 2030. The incorporation of production increases resulted in a "BAU" pathway with increased emissions to 2030. The pathways utilised a step approach to determine the potential emission reductions to be expected from certain activities.

3.8 Carbon neutral market research

A comprehensive research study was undertaken by Nature Pty Ltd and The Lab Insight and Strategy Pty Ltd to understand key insights and opportunities to inform future carbon neutral product development for the beef industry. The research was undertaken through a combination of qualitative and quantitative research across the supply chain, with a focus on the end consumer for domestic markets. Stakeholder interviews were utilised to identify opportunities, barriers and required areas of focus to enable carbon neutral product delivery.

In the qualitative study, interviews were conducted with five experts and five lead consumers. The experts were consulted on matters surrounding benefits of carbon neutrality, certification and accreditation, thought leadership and education, brand approach, consumer power and role, and process and communications. The lead consumers were consulted on their attitudes towards sustainability, carbon neutrality, food consumption, carbon-neutral (CN) brands and CN beef. In the quantitative study, an online survey was conducted targeting consumers aged 18–84, with 2000 respondents from the states of WA, NSW, VIC, and QLD, and an additional 2000 respondents from WA. A summary of the findings is included in this report.

4. Results and Discussion

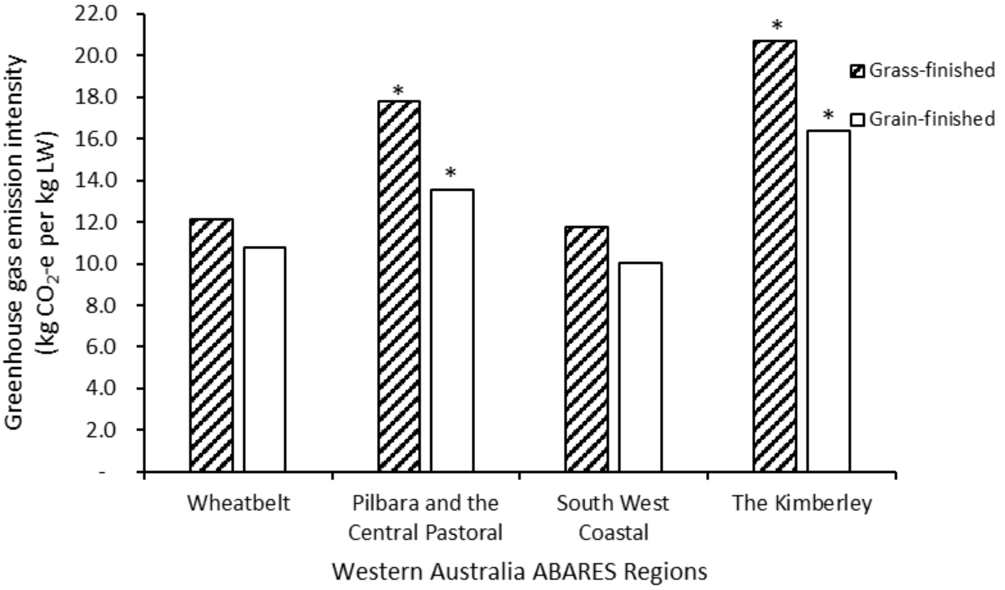
4.1 Supply chain baseline carbon footprint

Emission intensity – pre-processing

The mean GHG emission intensity for the Harvey Beef supply chain pre-processing was 12.1 kg CO_2-e kg LW^{-1} purchased by Harvey Beef, inclusive of grass finished and grain finished cattle. Emissions intensity differed between feeding type. The mean GHG emission intensity for grass-finished beef was 13.3 kg CO_2-e kg LW^{-1}, with a range of 11.8 to 20.7 kg CO_2-e kg LW^{-1} depending on the source region (Figure 7). The highest impacts arose from the Pilbara and the Central Pastoral region, but it is unlikely that these results accurately represent the general production in that region due to large numbers of other sales outside the Harvey Beef supply chain. Consequently, these results should be viewed with caution.

Mean GHG emission intensity for grain-finished beef was 10.7 kg CO_2-e kg LW^{-1} or 20% lower than the mean emission intensity of grass-finished cattle, principally because lifetime ADG and processing weight were higher than the grass-finished cattle. The GHG emission intensity in grain-finished cattle ranged from 10.0 to 16.4 kg CO_2-e kg LW^{-1}, and was primarily influenced by the region where the feeder cattle were sourced from (see Figure 7). When analysed separately, the mean emission intensity of feeder cattle prior to feedlot entry was found to be 14.1 kg CO_2-e kg LW^{-1}, which was higher than the comparative emission intensity of grass-finished cattle at 13.3 kg CO_2-e kg LW^{-1}.

Figure 7. Greenhouse gas emission intensity (kg CO_2-e per kg of LW sold) for grass-finished beef (hatched bars) and grain-finished beef (open bars) across the WA ABARES breeder regions; Wheatbelt, Pilbara and the Central Pastoral, South West Coastal and the Kimberley.

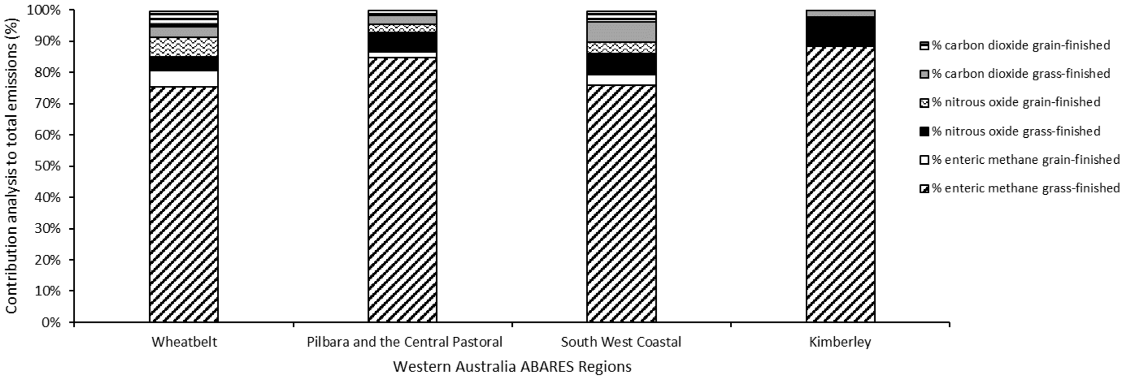


*

Results for the Pilbara and the Central Pastoral and the Kimberley were not representative of a stable herd due to large numbers of other sales outside the Harvey Beef supply chain. These results should be interpreted with caution.

The emission profile was dominated by enteric methane (av. 81%) followed by nitrous oxide (av. 10%) and carbon dioxide (av. 9%) (Figure 8). Emissions from grass-finished cattle and grain-finished cattle prior to feedlot entry dominated the emission profile. For example, on average, enteric methane from grass-finished cattle and grain-finished cattle prior to feedlot entry contributed 78% of emissions prior to processing, whilst enteric methane from grain-finished cattle while cattle were being finished contributed 3% of emissions.

Figure 8. Contribution analysis by gas (carbon dioxide, nitrous oxide and enteric methane) for grass-finished beef and grain-finished beef across the WA ABARES breeder regions; Wheatbelt, Pilbara and the Central Pastoral, South West Coastal and the Kimberley.



The mean GHG emission intensity of the HRG WA beef supply chain of 12.1 kg CO_2-e kg LW^{-1} was 13% lower than the national value reported for the processing herd for the year 2015 (13.8 kg CO_2-e kg LW^{-1}, updated with the most recent GWP_{100} values) reported by Wiedemann et al. (2019).

In this present study the GHG emission intensity was most influenced by production region, finishing system type (grass- or grain-finished) and herd productivity characteristics. Regional contrasts were key drivers of herd productivity performance (i.e. lifetime ADG, weaning percentage, mature cow weight, mortality and crude protein intake) and resulted in differences in emission intensity. Emission intensities were lower for the South West Coastal and the Wheatbelt due to higher weaning percentages and growth rates in these regions, even though these regions have high supplementary feed and fertiliser inputs. Emission intensity from cattle supplied from the Pilbara and the Kimberley were higher than the southern regions. These results were principally driven by the lower herd productivity (weaning rate and growth rate) in these regions compared to the south.

In this present study, grain-finished cattle had a 20% lower emission intensity than grass-finished cattle, which is similar to the difference found between grain and grass finishing in previous studies by Wiedemann *et al.* (2017). The mean grain-finished emission intensity of 10.7 kg CO_2-e kg LW^{-1} in this present study was similar to the grain-finished emission intensity reported for eastern Australia (9.9 kg CO_2-e kg LW^{-1} for short-fed export market updated with the most recent GWP_{100} values (Wiedemann *et al.* 2017) and the updated N_2O feed pad emission factor (Wiedemann and Longworth 2020; Commonwealth of Australia 2021). The lower emission intensity for grain-finished beef is associated with a higher feed conversion ratio of cattle during grain-finishing compared to grass-finishing, faster growth rates and consequently reduced age at processing, resulting in lower lifetime enteric methane and manure emissions (Wiedemann *et al.* 2017). Although there are higher energy inputs required to produce, transport and mill the feed inputs, the reduction in enteric methane more than compensates for this increase (Wiedemann *et al.* 2017).

The cow-calf herd prior to feedlot entry contributed up to 88% of emissions for the feedlot supply chain (Wiedemann *et al.* 2017) which was similar to the results here. While feedlots cannot directly influence emissions pre-feedlot, they may source more efficient feeder cattle to lower overall emissions. For example, most feedlots have specifications for around age at entry, and younger, heavier cattle will contribute to lower emission intensities for finished cattle. Cattle from higher productivity herds (higher weaning rates) will also produce lower emission intensity cattle. Conversely, the greatest impact from grain-finishing comes by grain-finishing cattle from poorer performing regions, where it is difficult to finish processing cattle in less than 3-4 years. This was shown in the present analysis, where the difference in emission intensity for grain-finished and grass-finished cattle from the Pilbara was greater than the difference in the southern regions. These results suggest if a north to south supply chain was to operate with feedlot finishing in southern WA, this is likely to result in an emission intensity reduction of 5 – 10% for cattle sourced from the Pilbara or Kimberley. This would result in similar supply chain dynamics that operate from the Northern Territory and north Queensland breeding operations, where cattle are moved to backgrounding operations in central Queensland before being finished in feedlots in south-east Queensland.

In the present study it was found that the age and weight of feedlot finished cattle was higher than grass-finished cattle. While higher finished weights in feedlots are typical in Australia, the higher age was unexpected because grain-finished cattle typically reach processing weight at much younger ages than the equivalent cattle on grass. One possible reason for this was that some grain-finished cattle may be poorer performing cattle that do not finish to processing weight during spring and are then held over into summer and autumn when they are finished on grain. Feed quality diminishes over summer in southern WA, and this is likely to result in low growth rates prior to these cattle entering a feedlot program. This was indicated by the estimated feeder cattle age and weight. Feeder cattle were older but lighter (lower lifetime ADG) than equivalent grass-finished cattle, resulting in a modest, 6% higher emission intensity than grass-finished cattle. One possible reason for this may be that these cattle grow at a slower rate while backgrounding over summer and autumn prior to feedlot entry. However, by grain-finishing these cattle, they can be turned off well before the next winter/spring when conditions would be suitable for grass-finishing. Considering this, grain-finishing may be disproportionately improving performance (i.e. reducing emissions intensity and total emissions) compared to if these cattle were grass-finished.

The mean emission intensity of the grass-fed WA beef supply chain was found to be similar to beef produced in NSW and QLD (Wiedemann, McGahan, Murphy, and Yan 2015) after updating the latter with the most recent GWP_{100} values. This outcome was driven by competing influences: in southern WA herd productivity was greater, but manure emissions and emissions from purchased inputs were also higher, resulting in similar emissions to NSW and QLD. Additionally, impacts from the Pilbara were higher, though confidence in these results was limited in the present analysis because of the small sample size and analysis of only part of the herd.

Studies have previously demonstrated the relationship between herd productivity factors and methane emissions intensity for beef cattle (Hunter and Niethe 2009), and more recently it was shown that the full emission profile could largely be explained by herd productivity factors; weaning percentage, ADG and crude protein in grass-finished beef in eastern Australia (Wiedemann, McGahan, Murphy, and Yan 2015). Additionally, heavier cows require higher maintenance feed requirements and consequently generate higher enteric methane and manure emissions. Diet crude protein was higher in the southern WA regions compared to Queensland and NSW, resulting in higher nitrous oxide emissions in the present study. Additionally, the QLD and NSW supply chains had very low levels of nitrogen available for leaching and runoff (fracWET) resulting in lower indirect nitrous oxide emissions.

Western Australian land use change

The present study did not include emissions and sequestration from soil or vegetation sources in the carbon footprint, because of the lack of farm-scale data available to quantify this. At the farm scale, emissions or sequestration from grassland, cropland and associated tree planting areas can result in widely varying levels of emissions or sequestration. Most previous carbon footprint research in Australia has assumed no change in soil carbon in grazing land, and vegetation soil carbon change has been shown to contribute emissions from land clearing in some parts of Australia (Henry *et al.* 2015), though emissions have decreased dramatically. At the national scale, soil and vegetation are now understood to be a net source of carbon sequestration (a negative emission) for the beef industry (Wiedemann et al. 2019) but such an analysis has not been completed for WA at the state level.

To gain insight into the potential carbon sequestration, the National Inventory data for Western Australia was reviewed, which revealed emissions of 1.4 Mt CO_2-e for grasslands and -2.9 Mt CO_2-e (sequestration) for cropland (AGEIS 2020). Forest land was -8.6 Mt CO_2-e (sequestration) (AGEIS 2020). Attribution of these emissions and sequestration sources is difficult: emissions from grassland may be attributable to cattle and sheep and possibly other industries or sectors, depending on the distribution. None-the-less, it is a potential emission source. Emissions from cropland are more easily attributed to grain production, and small amounts of this sequestration may be attributed to livestock via grain use in feedlots, for example. It may also be found that pasture/crop rotations contribute to sequestration in cropland, and that some of this sequestration is attributable to the pasture phase and therefore to livestock production. Lastly, forest land was a large sequestration source, potentially large enough to offset all emissions from livestock in WA, but the vast majority of this is expected to be associated with commercial forests, not farm forestry. For this reason, it is likely to be non-attributable to livestock, but noting the very large source of sequestration that this represents, further investigation into the degree of farm-forestry contributing to this emission rate would be warranted.

One source of carbon sequestration that may be under-represented in the National Inventory is on-farm tree planting. WA southern grazing regions have been strong advocates of tree planting, primarily to address salinity problems. This has resulted in carbon sequestration, but the scale of assessment used by the National Inventory most likely does not identify these small tree planting areas. The current contribution of these sources to the carbon balance of a farm is poorly understood. Wiedemann et al. (2016) found that shelter belts on a WA sheep farm may sequester carbon equivalent to around 2% of the emissions from sheep, when annualised over a 100-year timescale. This would be a more appreciable 6% if annualised over a shorter time period (30 years) that more closely aligned to the active growing period of the trees. Anecdotal evidence from farmer case study workshops conducted by DPIRD and Integrity Ag and Environment in 2020 suggested some farms may have planted up to 10% of land area to trees, and that more potential existed. This would most likely result in much more significant levels of carbon sequestration, approaching 30-50% of livestock emissions. Considering the magnitude of these emission and sequestration sources, further research is warranted to understand their contribution to the current carbon footprint of beef, and their potential to contribute to carbon neutrality.

Emission intensity – meat processing gate

After accounting for meat processing, the full supply chain emission intensity up to the point in which beef is ready for transport from the meat processing plant was 27.4 kg CO_2-e kg boxed beef^{-1}. Of this, 2.8% of emissions were from meat processing. The large increase in emission intensity from liveweight to boxed beef is caused by mass losses during processing, which resulted in emissions being attributed to much less product mass after processing than at the farm gate.

For benchmarking, the emission intensity associated with meat processing (processing impacts only, not including upstream beef production) was found to be 0.59 kg CO_2-e kg HSCW^{-1}.

Greenhouse gas emission intensity – boxed beef

The reported emission intensity for the supply chain, including meat processing, was 27.4 kg CO_2-e kg boxed beef^{-1}, which was above the range of previously published values for beef in eastern Australia of 24.4 to 26.2 kg CO_2-e kg boxed beef^{-1} (updated with the most recent GWP_{100} values and with transport emissions to the USA removed) reported in Wiedemann, McGahan, Murphy, Yan *et al.* (2015). This range was reported for grain-finished and grass-finished cattle respectively. The allocation method in the present study treated all edible output (i.e. boxed beef and edible offal) as part of the primary product for the purposes of allocation, following the recommendations from LEAP (FAO 2016). An economic allocation was applied for the remaining co-products. The same allocation method was used in Wiedemann, McGahan, Murphy, Yan, *et al.* (2015) and hence this does not explain the difference in impacts. The lower impacts reported in Wiedemann, McGahan, Murphy, Yan *et al.* (2015) is explained by a higher dressing percent compared to mid-range industry guidelines. According to the Meat and Livestock Australia Cattle Assessment Manual (2017), typical dressing percentages have a large range depending on class and P8 (mm) fat measurements. These include a reportable range of 48-58% for heavy steers, 50-59% for young cattle, and 42-56% for cows over 250kgs. The dressing percent used in this study was within these guideline ranges.

Meat processing contributed <3% of GHG emissions to total impacts from meat production. The emission intensity for the meat processing plant was similar to the range in benchmark data for the red meat industry of between 1 and 5% (Ridoutt *et al.* 2015). The industry average for scope 1 and scope 2 meat processing emissions was 0.43 kg CO_2-e kg HSCW^{-1} (Ridoutt *et al*. 2015). However, there was no allocation between products. The emission intensity (scope 1, scope 2 and scope 3) was 0.80 kg CO_2-e kg HSCW^{-1} in Wiedemann and Yan (2014), after the allocation of emissions to products. The Harvey Beef abattoir meat processing emission impacts were on par with this study.

4.2 Net emission reduction options

Overall, 53 options to reduce emissions or sequester carbon were screened. These are described in the next sections.

4.2.1 Screening of emission mitigation options

The outcomes of the emission reduction screening assessment are displayed in Table 5, Table 6 and Table 7. A total of 10 options focused on emissions reduction in a grazing system are shown in Table 5, 20 options to reduce emissions at feedlot facilities are shown in Table 6 , and 8 options to reduce energy and waste across the supply chain are shown in Table 7.

Options screened out were done so where multiple barriers to implementation were identified and there was no clear plan for these to be overcome in the next 5-7 years. However, this assessment reflects a point in time and should be periodically revisited to identify new options and re-assess options that have been screened out here, particularly if further R&D is done to overcome the barriers to adoption. As an example, Leucaena is currently screened out despite its strong mitigation and productivity potential, because there are regulatory restrictions on planting this in WA. However, if sterile Leucaena species can be developed this barrier would be overcome and it could be reintroduced into the plan.

Table 5. Screened options for emission mitigation in a grazing context, organised by emission source targeted and implementation timeline. H1 = horizon 1 (0-2 years); H2 = horizon 2 (3-5 years); H3 = horizon 3 (6-10 years)

Green = strong performance/opportunity, yellow = potential opportunity but some current limitations, red = critical challenges, low practical performance or unavailability

Strategy – Grazing	Emission source targeted	Technical mitigation potential & viability	Economically viable	Productivity benefits	ERF Potential	Available for implementation	R&D required	Other considerations	Screened supply chain (CN30)
Improved weaning & growth rates, reduced mortality	All	10%	Yes	Improved efficiency in stocking rates and product output	Available	Available	Ongoing research to determine best practices	Potential to improve emissions intensity through increased product output.	**H1-H3**
Improved Residual Feed Intake (RFI)	All	15%	Yes	Better feed conversion can lead to higher stocking rates	Potential	EBVs available for some but not all breeds	Ongoing research into heritability	Potential to reduce methane emissions & emission intensity.	**H2-H3**
Asparagopsis	Enteric Methane	TBC in grazing	Pending market information	Not known in a grazing context	Potential	5+ years	Mitigation needs to be confirmed in grazing. Feeding technologies are needed.	High potential however unknowns on mitigation and distribution for grazing	**H3**
Bovaer (3-NOP)	Enteric Methane	TBC in grazing	Pending market information	Not known in a grazing context	Potential	5+ years	Mitigation needs to be confirmed in grazing. Feeding technologies are needed.	High potential however unknowns on mitigation and distribution for grazing	**H3**
Dietary Fat/Oils	Enteric Methane	10%	Potential	Good supplementary feed source	Potential	Available	Nil	Limit to a maximum of 7% of dietary intake. Challenging to distribute in grazing.	**Out**
Nitrate	Enteric Methane	7%	No	No net positive or negative effect	Available	Available	Nil	Risk of nitrate toxicity. Nitrate use is expensive and ineffective due to regulation.	**Out**
Desmanthus	Enteric Methane	0-10%	Yes	Improved growth rates and potentially soil carbon	Potential	Available	Further research required on mitigation potential	Sub-tropical species may not be suited to regions outside the Kimberley's. Mitigation potential variable.	**Out**

Leucaena	Enteric Methane	21%	Yes	Improved growth rates and potentially soil carbon	Potential	No. Illegal in WA	Research needed to develop sterile variety	Mitigation potential limited by the percentage of Leucaena in the sward, and the amount of grazing time that animals can spend on Leucaena.	**Out**
Eremophilia	Enteric Methane	15%	Limited commercial spp.	No net positive or negative effect	No	Limited commercial spp.	Required on mitigation potential, productivity and commercial spp. before this can be implemented	Drought, frost and grazing tolerant	**H3**
Forage Brassicas	Enteric Methane	43%	Yes	Improved growth rates	No	Available	Nil	Option for backgrounding in southern WA. Potential negative effects on animal health.	**H2**

Table 6. Screened options for emission mitigation in a feedlot context, organised by emission source targeted and implementation timeline. H1 = horizon 1 (0-2 years); H2 = horizon 2 (3-5 years); H3 = horizon 3 (6-10 years)

Green = strong performance/opportunity, yellow = potential opportunity but some current limitations, red = critical challenges, low practical performance or unavailability

Strategy – Feedlot	**Emission source targeted**	**Technical mitigation potential & viability**	**Economically viable**	**Productivity benefits**	**ERF Potential**	**Available for implementation**	**R&D required**	**Other considerations**	**Screened supply chain (CN30)**
Dietary Fat/Oils	Enteric Methane	15%	Yes	Typically fed to maximise energy density in finisher rations	Potential	Available	Nil	Limit to a maximum 7% of dietary intake	**H1**
Bovaer (3-NOP)	Enteric Methane	71%	Pending market information	Improvement in FCR of 3-5%. No proven improvement in other productivity aspects.	Potential	1-2 years	Efficacy limited in starter rations, which could be improved in response to further research. Further research will improve knowledge of effective feeding strategies.	Nil	**H2**
Asparagopsis	Enteric Methane	85%	Pending market information	Improvement in FCR of 9-14% from one study. No proven improvement in other productivity aspects.	Potential	3-4 years	Efficacy may be limited in starter rations, which could be improved in response to further research. Further research will improve knowledge of effective feeding strategies. Research needed to reduce cost.	Nil	**H3**

High concentrate diets	Enteric Methane	30%	Yes	Increased weight gain	No. Likely to be considered current practice	Available	Research may be needed to confirm maximum safe levels of grain in rations	More information on safety and cost-effectiveness would be beneficial	**Out**
Nitrates	Enteric Methane	7%	No	No net positive or negative effect	No	No	Nil	Risk of nitrate toxicity.	**Out**
Ionophores	Enteric Methane	9%	Yes	Potential increased ADG and feed efficiency	No	Available	Required on mitigation potential	Commonly used. Mitigation results have been variable	**Out**
Bacteriocins & Acetogens	Enteric Methane	50%	No	Unknown	No	10+ years	Long-term research required	May have some potential but efficacy & rumen adaptation needs to be confirmed	**Out**
Probiotics	Enteric Methane	13%	Maybe	Unknown	No	Available	Required on mitigation potential	Displays potential, and mitigation results may be higher than initially believed	**Out**
Vaccination	Enteric Methane	30%	No	Unknown	No	5-10 years+	Required on suitability to differing climates	More work needed on effectiveness in Australian conditions	**Out**
Inoculants	Enteric Methane	9%	No	Unknown	No	Unknown	Required on mitigation potential	More work needed on effectiveness in Australian conditions	**Out**
Low protein (nitrogen) diets	Manure Management System – Ammonia*	24-45%	No	No	No	Available	Further research required on mitigation potential	Targets a small emission source but has benefits throughout MMS	**Out**
Acidification	Manure Management System – Ammonia*	14-100%	No	No	No	Not currently practiced	Limited effectiveness. Research not warranted	May be beneficial to increase N in manure for cropping. Impacts in land application unknown.	**Out**
Sorbers	Manure Management System – Ammonia*	50-90%	No	No	No	Available	Limited effectiveness. Research not warranted	Would be high cost and may increase feed pad moisture.	**Out**
Rapid cleaning (<30 days)	Manure Management System – Nitrogen	19%	No	No	No	Available	Limited effectiveness. Research not warranted	Could be beneficial for waste-to-energy projects but otherwise difficult to justify the added cost.	**Out**

Nitrification inhibitors	Manure Management System – Nitrous oxide	70%	No	No	No	Not currently available	Target emission source is relatively small. Research not warranted	Expensive for the outcome achieved and requires another management activity	**Out**
Short duration stockpiling	Manure Management System – Nitrous oxide, methane & ammonia*	75%	No	No	No	Available	Target emission source is relatively small. Research not warranted	Could be done. May result in higher land application emissions.	**Out**
Cover stockpiles	Manure Management System – Nitrous oxide, methane & ammonia	99% nitrous oxide, 88% methane, 12% ammonia	No	No	No	Available	Target emission source is relatively small. Research not warranted	Could be done. May result in higher land application emissions.	**Out**
Thermal energy (combustion, pyrolysis)	Manure Management System – Nitrous oxide, methane & ammonia & displaced energy	10-20% stockpile emission reduction & 100% displacement of boiler gas	No	No	No	Not currently available	Difficult to implement and saves only small amounts of emissions. Further research not warranted	Combustion has been used in the USA but requires very low soil contamination in scraped manure. Has not been successfully done in Australia. Pyrolysis is high cost, generally unproven and has the same problems with soil contamination.	**Out**
Pond cover and methane destruction	Manure Management System – Methane & displaced energy	100% pond emissions, displacement of boiler gas	No	No	No	Available	Targets a very small emission source. Further research not warranted	Ponds are constructed for runoff control and are difficult to reconfigure for methane capture.	**Out**
Short retention time	Manure Management System – Methane	25-50% of pond emissions	No	No	No	Available	Targets a very small emission source. Further research not warranted	Needs to comply with other environmental regulations for nutrient management	**Out**

Table 7. Screened options for emission mitigation focusing on energy-based emissions, organised by emission source targeted and implementation timeline. H1 = horizon 1 (0-2 years); H2 = horizon 2 (3-5 years); H3 = horizon 3 (6-10 years)

Green = strong performance/opportunity, yellow = potential opportunity but some current limitations, red = critical challenges, low practical performance or unavailability

Strategy – Energy	Emission source targeted	Technical mitigation potential & viability	Economically viable	Productivity benefits	ERF Potential	Available for implementation	R&D required	Other considerations	Screened supply chain (CN30)
Solar Energy Grazing	Energy	80%	Payback periods often 3-5 years	N/A	N/A	Available	Improvements in efficiency and battery storage are continuously improving	Requires individual location suitability analysis from energy contractor	**H1**
Solar Energy Feedlot	Energy	80%	Payback periods often 3-5 years	N/A	N/A	Available	Improvements in efficiency and battery storage are continuously improving	Requires individual location suitability analysis from energy contractor	**H1**
Solar Energy Meat Processing	Energy	10%	Payback periods often 3-5 years	N/A	N/A	Available	Improvements in efficiency and battery storage are continuously improving	Requires individual location suitability analysis from energy contractor	**H1**
Greenpower Grazing	Energy	20%	Additional cost ranges from 3-8c/kWh	N/A	N/A	Available	None	May be more expensive than other options	**H1**
Greenpower Feedlot	Energy	20%	Additional cost ranges from 3-8c/kWh	N/A	N/A	Available	None	May be more expensive than other options	**H1**
Greenpower Meat Processing	Energy	90%	Additional cost ranges from 3-8c/kWh	N/A	N/A	Available	None	May be more expensive than other options	**H1**
Covered Pond meat processing	Energy	100%	Yes	Replaces some gas & removes effluent emissions	Available	Available	None	Ongoing work to improve efficiency and energy yield is warranted	**H1**
Vehicle efficiency upgrades	Energy	20%	Upgrading machinery can be expensive	N/A	N/A	Efficient vehicles available, battery powered likely 10+ years off	Significant R&D for renewable powered farm machinery needed	Smaller part of emissions profile, expensive to integrate	**Out**

4.2.2 Screening of carbon sequestration options

Soil carbon sequestration

Soil carbon sequestration may be an option to address part or all of the residual emissions from the supply chain. There are numerous practices which can increase soil carbon, with 9 of these screened in Table 8.

Table 8. List of screened potential soil carbon practices that could be administered to increase soil carbon. H1 = horizon 1 (0-2 years); H2 = horizon 2 (3-5 years); H3 = horizon 3 (6-10 years)

Soil carbon sequestration	Technical viability	Economic viability	Productivity benefits	Available for implementation?	R&D required	Other considerations	Screened (supply chain CN 2030)
Prevent wind/water erosion	Yes	Yes	Soil protection	Available	Nil		**H2-H3**
Claying	Yes	No	Improved nutrient retention	Maybe	Nil	Availability of suitable clay source is challenging, limited to specific locations	**H2-H3**
Liming	Yes	Site specific	Improved pasture production	Available	Nil	Availability of suitable lime source is challenging, limited to specific locations	**H2-H3**
Green manuring	Maybe	Generally no	Improved soil health	Available	Nil	Limited data on carbon benefits	**H2-H3**
Biochar	Yes	No	Improved soil health	No	Required for scale and affordability	Expensive, hard to obtain, can be contamination risks. Could be a good longer-term option	**H2-H3**
Perennial pastures	Yes	Yes	Less acidification, out of season feed	Available	Nil	Requires operational management changes	**H2-H3**
Composting	Yes	Yes	Improved soil health	Available	Nil	Required structural investment to make onsite	**H2-H3**
Rotational Grazing	Yes	Yes	Increased productivity and pasture health	Available	Nil	Requires operational management changes and extensive fencing.	**H2-H3**
Manure application	Yes	Yes	Improved soil health	Available	Nil	Needs to be done in line with environmental requirements	**H2-H3**

Southern WA is characterised by sandy soils, reliable rainfall, and warm temperatures and these will determine potential carbon sequestration, especially with a changing climate. It is estimated that it could take over a decade to detect significant changes in SOC in South West WA because of these factors, as well as high spatial and temporal variability (Department of Agriculture and Food 2013).

Few studies exist on carbon sequestration from manure application to Australian soils. Redding et al. (2015) examined multiple studies on manure applications and found a range of 3 to 50% of carbon in manure may be sequestered in soil after land application. Redding et al. (2015) applied cattle manure to a range of agricultural soils in Queensland. Carbon retention ranged from 30 – 60% of applied manure carbon. However, carbon sequestration of applied manure is expected to be lower in light-textured soils and may not always result in significant increases in sequestered carbon (Fontaine and Barot 2005; Fontaine *et al.* 2007).

It can be expected that perennial pastures may have greater potential for C sequestration than fodder cropping systems due to a higher root:shoot ratio stimulating higher below ground biomass. Additionally, there is greater potential for C sequestration in pasture systems than cereal cropping systems, as long as pastures are grazed at appropriate stocking levels that stimulate the turnover of above-ground shoots and below-ground roots (Sanderman *et al.* 2010).

Due to the uncertainty in the potential soil carbon sequestration rates across different regions and locations within WA, and the conservative potential of soil carbon sequestration in Australian soils, further work is required to understand the opportunities for soil carbon sequestration across the third party supply chain. For the carbon neutral pathways in this report, it was estimated that 20% of residual emissions could be offset by soil carbon storage. This is likely to be constrained to the Agricultural region where rainfall is sufficient to achieve higher carbon inputs, and also because WA pastoral regions are currently restricted from participating in ERF soil carbon projects because of restrictions on change of land use on pastoral leases.

Soil carbon projects may show promise, however currently there are significant costs associated with assessing soil carbon change. Current ERF soil carbon projects are very expensive, and costs are particularly significant when measuring small change over large areas such as in pastoral zones. For the beef industry, this is currently a critical gap. Lower-cost measurement will be a critical need for assessing soil carbon change and implementing soil carbon projects to offset residual emissions across the supply chain.

Vegetation carbon sequestration

Vegetation carbon sequestration will be required to address the gap between residual emissions and soil carbon sequestration, and meeting net zero and carbon neutral goals. There are numerous vegetation projects that can be undertaken under the ERF. Table 9 demonstrates the ERF methodologies that include activities to sequester carbon in vegetation.

Table 9. List of screened ERF vegetation methods. H1 = horizon 1 (0-2 years); H2 = horizon 2 (3-5 years); H3 = horizon 3 (6-10 years).

Strategy - vegetation carbon sequestration - ERF methods	Activity category	Included activities	Other comments	Screened (supply chain CN 2030)
Human-Induced Regeneration of a Permanent Even-Aged Native Forest (2013)	Re-establishment of native forest cover	A change in land management (e.g. a change in grazing management; cessation of regular clearing; control of feral browsers) that facilitates the natural regeneration of forest cover[1] from an initial non-forest state.	Requires changed management practices that remove the identified suppression activity, allowing the attainment of forest cover	**H2-H3**
Native Forests from Managed Regrowth (2013)			Has restrictions on grazing. Likely to be very little land available in WA that is suitable.	**Out**
Reforestation by Environmental or Mallee Plantings - FullCAM (2014)	Planting of new forests	The establishment of forest cover on currently non-forested land, via direct seeding and/or planting of tube stock seedlings. The methods include environmental plantings, as well as the establishment of commercial plantation species.	Requires suitable land areas to be set aside for plantings. Restrictions on grazing and land use. Better in higher rainfall and strong tree growth areas.	**H2-H3**
Reforestation and Afforestation (2015)			Requires field measurements, increased cost of management	**Out**
Avoided Deforestation (2015)	Protection of existing forests	Includes the cessation of land clearing to facilitate forest recovery (Avoided Clearing), and the protection of existing forest cover through relinquishment of clearing permits awarded for the purposes of converting forest cover to cropland or grassland (Avoided Deforestation).	Requires land with forest cover, required field measurements, and likely less available than other methods	**Out**
Avoided Clearing of Native Regrowth (2015)			Requires existing forest cover, on land that has been previously cleared and could be cleared again.	**H2-H3**

[1]Forests include all vegetation with a tree height of at least 2 metres and crown canopy cover of 20 per cent or more, over an area of at least 0.2 ha

The screening assessment identified ERF methods were limited in scope to quantify and attribute stored carbon to landholders. For example, the most popular ERF method in Australia, Human-Induced Regeneration (HIR), is only applicable for land that had less than 20% canopy cover over the last 10 years, with no scope to consider forests that are degraded and have sequestration potential through regeneration of areas where canopy cover exceeds 20% but is still well below full forest cover. International methods may support these areas where the ERF currently does not. Similarly, under the ERF there are strict requirements excluding the quantification of sequestration in areas of forest that cannot be cleared for regulatory reasons. Other mechanisms that can enable beef supply chains to quantify and claim the sequestration from these sources would be transformational for the industry, while better reflecting the actual carbon balance of grazing enterprises.

Considering this, there is the potential for significant sequestration to be occurring on landholders properties that is not currently able to be quantified under existing ERF methodologies and which is therefore difficult to integrate into a market program. New strategies are required to quantify vegetation sequestration in these areas and this should be considered as an additional work area.

4.3 Carbon reduction pathways: supply chain

Future pathways

The three pathways modelled to 2030 are shown in Table 10. The pathways utilised a step approach to determine the potential emission reductions to be expected from certain activities.

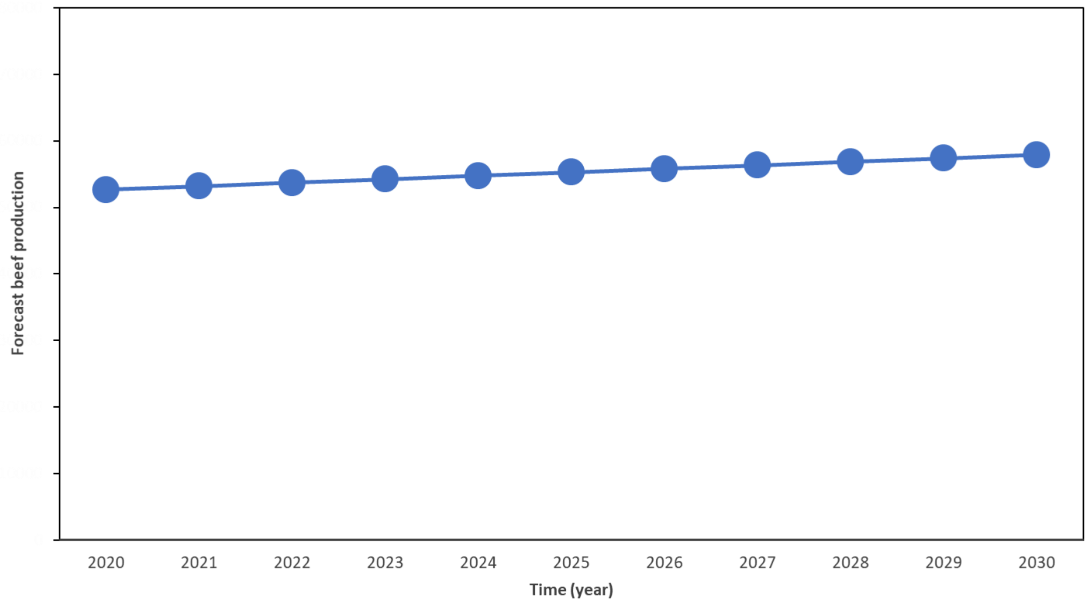
Table 10. Emission mitigation pathways for the supply chain

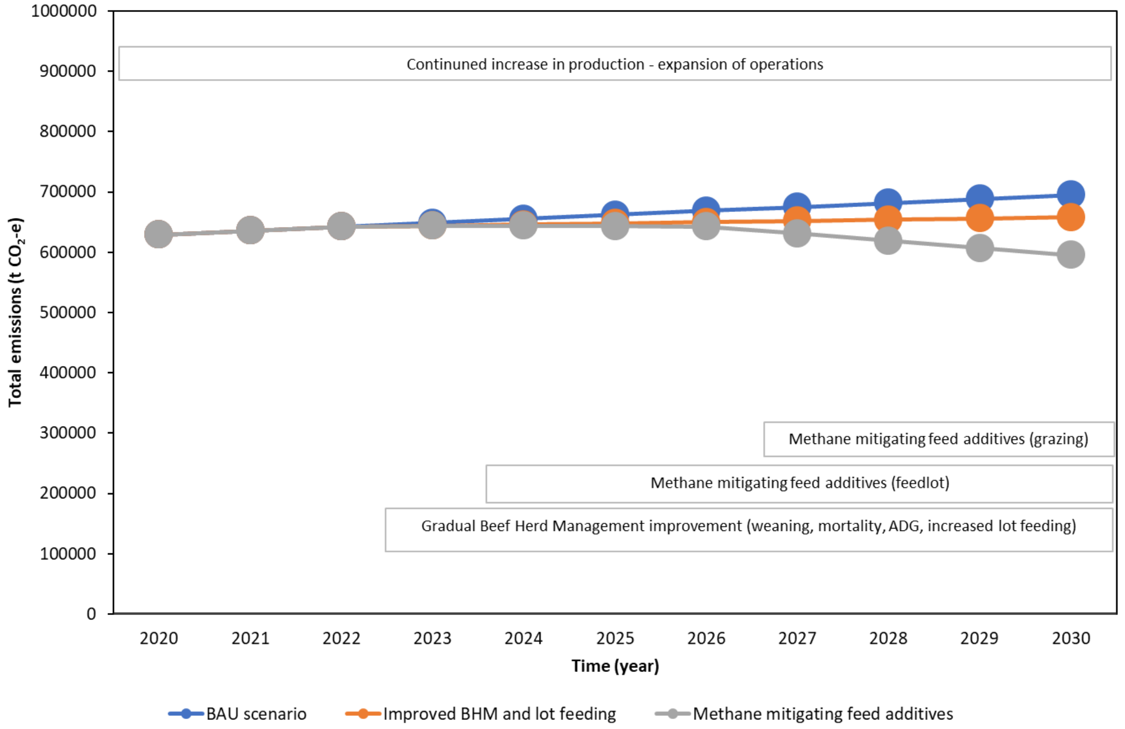
Strategy	Description
Pathway 1 (P1)	BAU emissions approach. Expected expansion in beef supply based on industry estimates.
Pathway 2 (P2)	Beef herd management improvements undertaken (herd improvement via better weaning rates, higher turnoff weight, faster turnoff, improved mortality). Expansion of grain feeding.
Pathway 3 (P3)	P2 + methane mitigating feed additives and supplements across the supply chain at different intervals (grain-feeding and grazing).

For the supply chain, the expected production increases and emissions forecasts for each pathway through to 2030 are represented in Figure 9, top and bottom respectively. This includes emission increases due to expansion of production and beef productivity increases through herd management improvements. The expected production increase was 10% which is in line with estimated projections to expand the value of beef over the coming decade in alignment with general industry goals (Meat & Livestock Australia 2020).

The three scenarios display the relative impacts of various activities when compared to a baseline "no action" pathway. Pathway 2 provides a reduction of 5.3% from the baseline and pathway 3 provides a reduction of 14.3%.

Figure 9. Top: Estimated forecast production through to 2030, including beef production expansions. Bottom: Emission mitigation pathways for the supply chain to 2030, including emission increases from expanded production



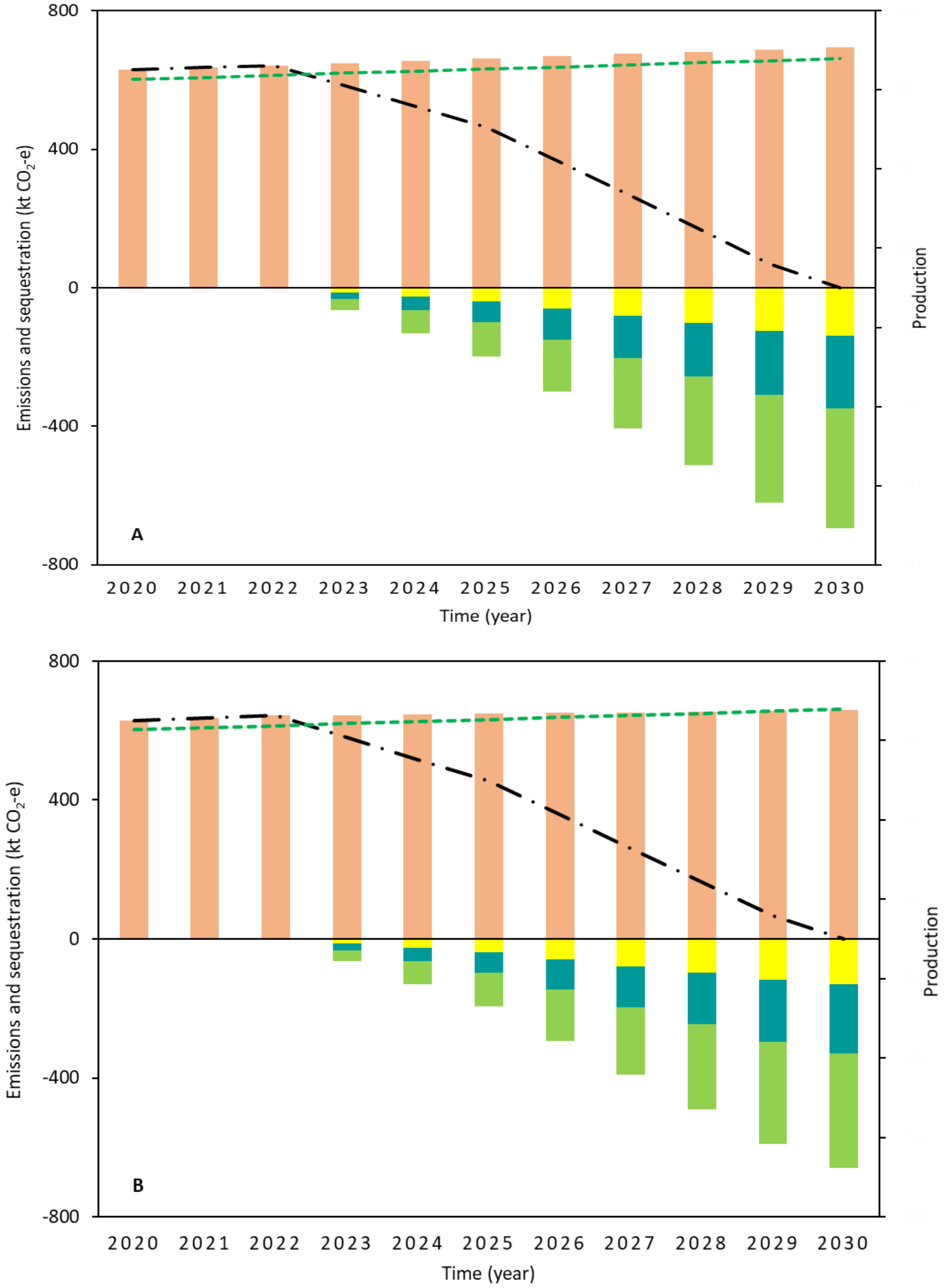


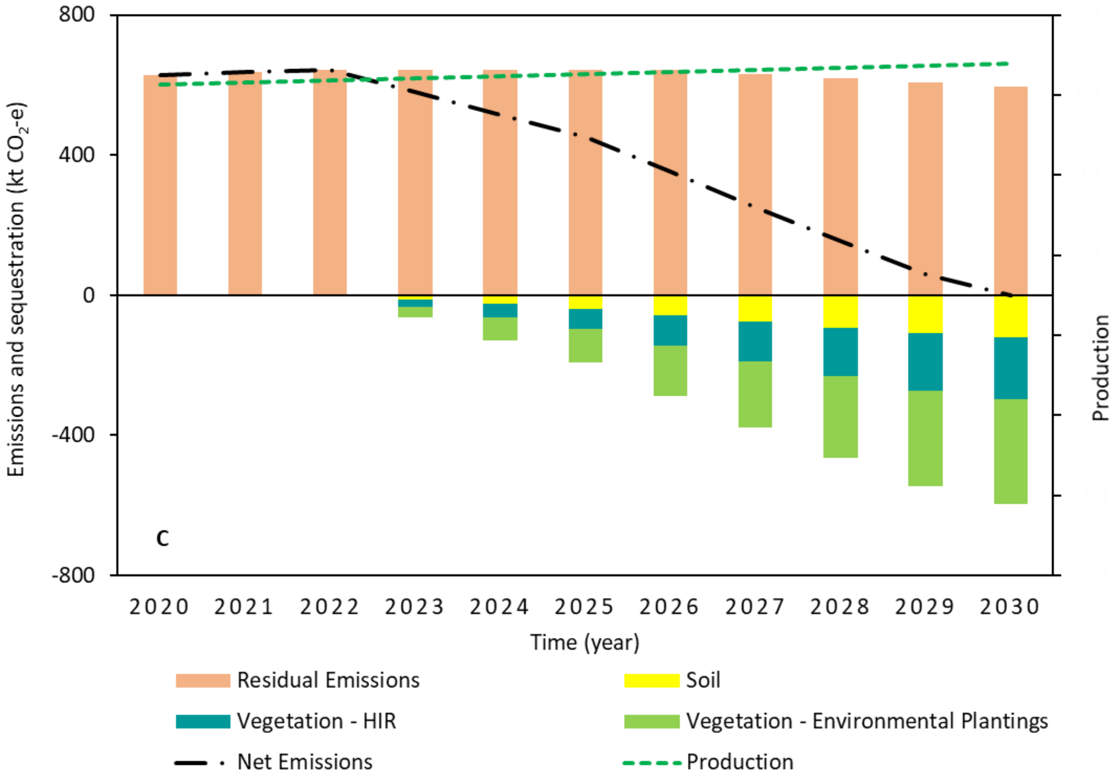
Emissions and mitigations were dominated by methane. Given this significant role of methane within the emissions profile of the supply chain and the challenges in achieving large-scale mitigation, further consideration is warranted around applying different accounting metrics, such as GWP* to assess impacts on the climate. The potential for different accreditations under "Climate Neutral" could potentially cause a significant shift in impact reporting, though establishing this method as a credible accounting construct will require significant further research and development.

Mitigation and sequestration pathways to carbon neutral

As the emission mitigation and production pathways do not achieve a carbon neutral emission outcome, soil and vegetation sequestration were modelled to determine the required actions to achieve carbon neutrality by 2030. As soil and vegetation practices and opportunities vary significantly by region and production types, an assumption was made to split these opportunities across potential options available across the supply chain. In this case, 20% was achieved by soil carbon sequestration, 30% via HIR, and 50% via environmental plantings.

Figure 10. Emission mitigation and sequestration pathways required to achieve net zero by 2030. A: Pathway 1. B: Pathway 2. C: Pathway 3.





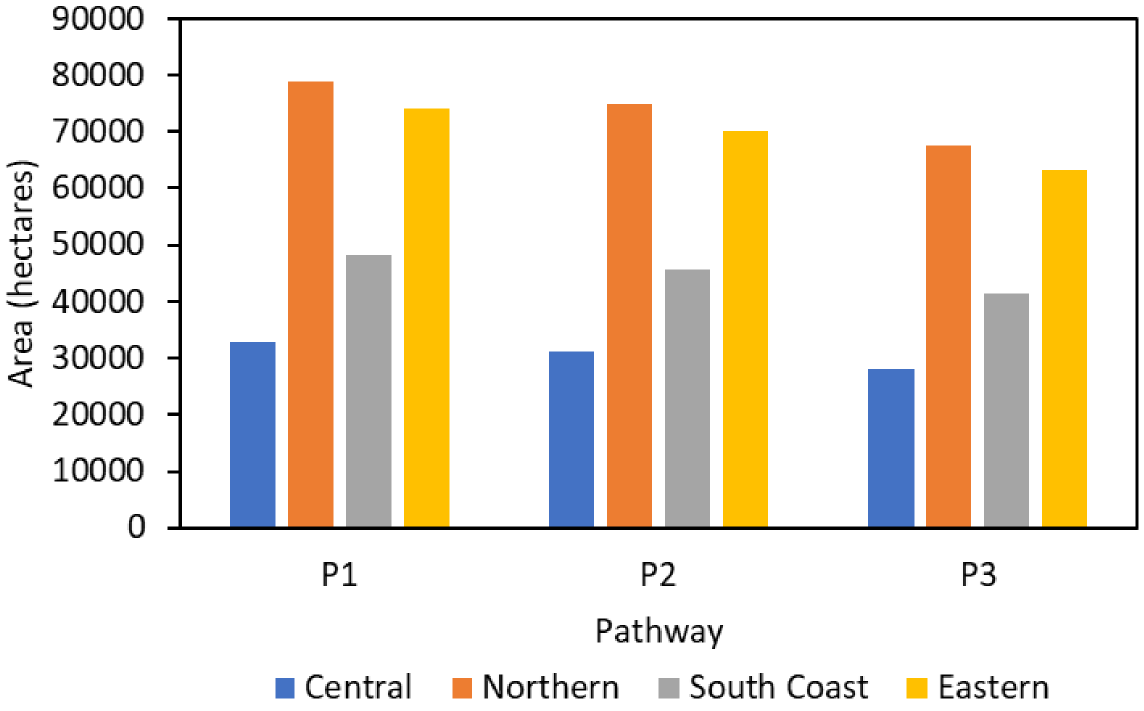
Sequestration rates for mixed environmental plantings across different regions of WA were utilised to determine the indicative hectares required for the relevant portion of the emission pathways. As the third party supply chain is extensive and across most of WA, further work is required to determine opportunities for vegetation carbon sequestration across supply chain properties. Potential land area required is displayed in Table 11 and Figure 11.

Table 11. Mixed environmental planting sequestration rates across different regions of WA for different planting areas (block or belt) from FullCAM, and indicative land areas required by each pathway if 100% of the requirement came from this region (i.e. land areas are not additive).

Low and high sequestration ranges reflect the results for different locations within these regions, highlighting the potentially variability across different localities. The indicative land required shows the hectares required for a particular pathway if a specific region was utilised to provide the tree plantings. This is an approximation only for comparative purposes.

Mixed environmental plantings	**Block** (t CO_2-e.ha^{-1}·yr$^{-2)}$		**Belt** (t CO_2-e.ha^{-1}·yr$^{-2)}$		**Midpoint** (t CO_2-e.ha^{-1}·yr$^{-2)}$	**Indicative land required (ha) for plantings** (50% of total required sequestration) in each pathway		
WA region	Low	High	Low	High		P1	P2	P3
Central	3.7	11.5	5.6	17.6	10.6	32781	31033	28083
Northern	3.4	3.6	5.2	5.5	4.4	78973	74762	67654
South Coast	2.3	8	3.4	12.1	7.2	48262	45688	41344
Eastern	2.9	4.3	4.4	6.6	4.7	73933	69990	63336

Figure 11. Indicative land required (ha) for mixed environmental plantings to achieve 50% of the sequestration required for each pathway broken down by WA region

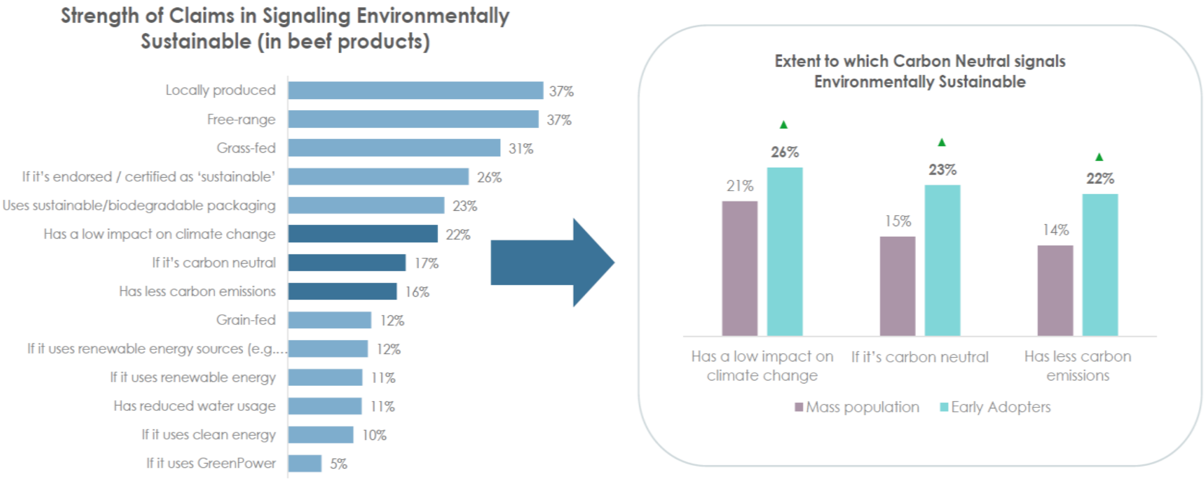


4.4 Carbon neutral market research

The study revealed that while general understanding of environmental sustainability is high (69%), understanding of carbon neutrality is lower (52%) especially when regarding the meat industry (23%).

Instead, consumers are usually more drawn to sustainability solutions that have consumer-facing impacts or are simpler to comprehend, such as reduced plastic packaging or the utilization of renewable energy. Specifically, when purchasing beef products, “locally produced” and “free-range” are considered the strongest indicators of sustainability (Figure 12). This highlights the need for further education of the public to increase awareness of the purpose and role of carbon neutral beef in achieving sustainability goals.

Figure 12. Responses to the question “Thinking about sustainability in the context of buying beef products, what signals to you that a beef product is environmentally sustainable?”



Statements from consumers were obtained to identify why they may or may not choose carbon neutral product offerings (Figure 13). Key reasons consumers may reject carbon neutral offerings were related mainly to price, and a lack of knowledge around carbon neutrality and a mistrust of brands. Key reasons consumers may choose these offerings relate to a desire to help the planet, and some understanding that the beef industry may have a high impact on emissions.

Figure 13. Consumer statements reflecting reasons for either rejecting or accepting carbon neutral offerings

Reason for not choosing Carbon Neutral

‘**Why I should pay more** for the low carbon?’

‘**It is cheaper** and I don’t think it makes any difference.’

‘**The price is the only deciding factor** because **climate change is a hoax**’

‘**I’m not into any of these new "Carbon Neutral" things**, I believe they are actually **worse for you then the regular mince meat.** Everything seems to be too precious these days, including the food we eat.’

‘**Do not trust the claim**’

‘**I don’t know what carbon neutral beef mince is** and how it is worth paying more for’

‘We have a 0.01% CO2 omission here in Australia and we **cannot do much more to cut down that figure**’

Reason for choosing Carbon Neutral

‘I’m concerned about the impact of my eating meat has on the environment so **if I can do something to help offset that I’m willing to pay for it**’

‘**Worth that few extra cents** to achieve this positive climate outcome whilst also enjoying a mild luxury treat’

‘**I know that the meat industry is affecting the climate/ environment in many ways** and if we have a beef mince that is emitting low carbon while being processed, I would go for it!’

‘**Responsibility to care for the climate** in what ever way I can even at an extra cost’

‘**It is not that much more expensive** at the end of the day and the **meat industry is a huge contributor** to pollution, so I would appreciate anything that reduces that’

‘I think climate positive beef mince is **much healthier**’

A major obstacle to achieving carbon neutrality is the willingness of consumers to pay for the cost associated with greener production of food. Consumers have mixed reactions towards the pricing of carbon neutral beef, with some suggesting that sustainable products should be competitively priced to match that of the general market, while others expect a small price premium and would be open to paying more for a greener product. However, the panel of experts warned that early in-market experience shows that while consumers may claim they are open to paying more, there is limited flexibility when it comes down to the actual, specific pricing. Despite the importance of sustainability to most consumers, the additional cost of these products makes it difficult to choose sustainable options. Among the survey respondents, 57% expressed that it was “just too expensive” to do the right thing for the environment all the time, while 26% will always choose the sustainable and eco-friendly option. This market segment of ‘Early Adopters’ (1 in 4 consumers) indicated that they are willing to pay 15% more for a carbon neutral beef option, which is reduced to 1 in 5 consumers when the price premium of the carbon neutral beef option is set at 30%. These results were consistent across two beef products used in the survey (beef mince and porterhouse steaks).

The ‘Early Adopters’ target market of environmentally-conscious consumers generally represents a demographic of 25–34 years old couples with young children (under 15 years old) living at home. Interestingly, this group indicated that they are more likely to purchase shellfish instead of other meat alternatives such as chicken and bacon. They also indicated that they are current customers of a range of sustainable and ‘carbon-neutral’ brands.

The journey to carbon neutrality may provide diverse benefits to HRG and industry. However, there are some less obvious benefits of carbon neutrality that are understood by few consumers which featured strongly in expert conversations during the qualitative study. These include:

- **More efficient operations -** Operations would be smoother if products are being produced and distributed more locally with full oversight of the supply chain.
- **Mitigated risk -** Companies reduce their exposure to problems like energy shortages or high pricing.

The key insights discovered during the qualitative study were:

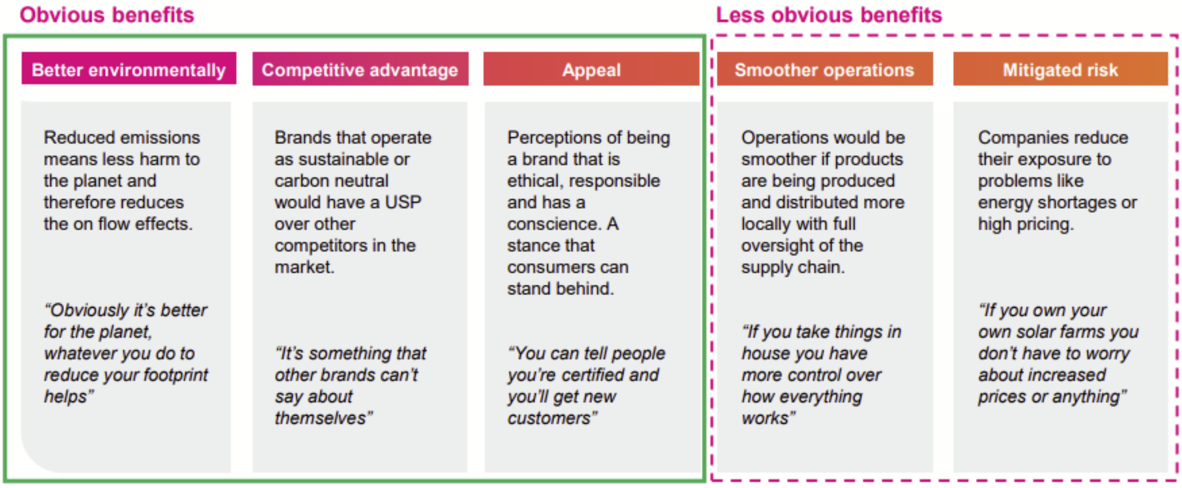
- People care deeply about sustainability and are changing their behaviours to be more eco-conscious:
    - Consumers are making concerted and conscious efforts to be more sustainable where possible, including incorporating sustainable and carbon conscious behaviours in all areas of life (such as both in and outside the home).
    - This approach extends to their product search, considerations and purchases, such as: seeking out second hand products; avoiding single use plastic bags; purchasing products that have less packaging; buying sustainably caught proteins; buying direct from local markets; buying in bulk or taking their own containers; and looking out for certification logos.
- Carbon neutrality is not well understood. It is a new concept that has little presence in the market:
    - Carbon neutrality is understood at a conceptual level, but the practicalities are hazy.

  - Consumer understanding is relatively consistent across topics such as what carbon emissions are, the impact they have on the planet (in this case, raising temperature), and neutrality meaning a reduction of carbon emissions to a point of zero.
  - Consumer understanding is limited across the detail and process, such as what carbon offsetting is, how it's done (the process), what carbon credits are, and the types of projects being run.
  - The term is often conflated with other similar concepts, falling under the broader umbrella of sustainability.
  - Personal carbon reduction is hard to quantify, but consumers are often able to see a raft of co-benefits to actions. For example, when walking or cycling instead of driving, there are no emissions released and there are added health benefits.
  - Some benefits are immediately identifiable, with others requiring further promoting (as per Figure 14).
- Carbon neutrality is not something that people expect from brands or prioritise right now:
  - Lead consumers are conscious about the impact of carbon products, however it is early days for carbon neutral food and there are limited food products available on the market for consumers to seek out or benchmark against other products.
  - Consumers are responsive and open to the prospect of carbon neutral food entering the market, however at this stage it is more a 'nice-to-have'.
  - A total carbon neutral status feels like a goal that is years off from being achieved, with consumers wanting smaller positive changes they can see right now.
- Consumers are the driving force behind sustainability action and brands are currently the driving force behind carbon neutrality:
  - Consumers are increasingly looking to brands to help them live more sustainably, and expect brands to be implementing the sustainability changes that are achievable for them.
  - The largest onus is on businesses that deal directly with fossil fuels or are heavy carbon emitters, including mining, energy, transport, meat and food, and fashion and textiles.
  - Consumers want general sustainability action, including the reduction of resource use and waste. However, it is being driven by brands that are thinking ahead and attempting to anticipate the future of consumer's preferences and shareholder preferences.
- In the transition to carbon neutrality, communication and messaging needs to be watertight and consistent:
  - Regardless of the plan of action being taken, brands and industries must be transparent and real, with consumers wary of 'greenwashing'.
  - Seven guiding principles for communications were identified, as displayed in Figure 15.
  - Consumers have expectations relating to packaging and product: reducing unnecessary plastic packaging; utilization of vacuum packed or cardboard exterior packaging to reduce other unnecessary packaging; the utilization of attention-grabbing sustainability words; incorporation of a tick of carbon neutrality certification; quickly identifiable sustainable visual cues; and location or origin.
  - Pre-certification, consumers want to understand what is happening right now: understanding overall brand sustainability goals; the process they are taking to a

carbon neutral position; the motivations of the brand to be acting sustainably; and a personal story relating to the farm and/or the farming community.

- Post-certification, consumers want to identify: visual certification evidence; practical procedures being undertaken operationally to sustain carbon neutrality status; tangible metrics such as the environmental before vs now in real numbers; the positive of change to the business; changes to the product or lack thereof, such as taste or portion sizes; and accessibility of the products.

Figure 14. Consumer understanding of obvious and less obvious benefits of carbon reduction actions



Obvious benefits

Better environmentally

Reduced emissions means less harm to the planet and therefore reduces the on flow effects.

"Obviously it's better for the planet, whatever you do to reduce your footprint helps"

Competitive advantage

Brands that operate as sustainable or carbon neutral would have a USP over other competitors in the market.

"It's something that other brands can't say about themselves"

Appeal

Perceptions of being a brand that is ethical, responsible and has a conscience. A stance that consumers can stand behind.

"You can tell people you're certified and you'll get new customers"

Less obvious benefits

Smoother operations

Operations would be smoother if products are being produced and distributed more locally with full oversight of the supply chain.

"If you take things in house you have more control over how everything works"

Mitigated risk

Companies reduce their exposure to problems like energy shortages or high pricing.

"If you own your own solar farms you don't have to worry about increased prices or anything"

Figure 15. Seven guiding principles for communication relating to carbon neutrality

Be true to your brand

Make sure it's relevant to your customers and what they care about.

Keep it real

Talk in practical, down-to-earth terms not lofty metaphors or 'marketing talk'.

Keep it positive

Keep it solution focused rather than about the issues.

Be watertight

Make sure that everything we say is 100% true and able to be proved.

External validation is important

Work with experts to drive credibility.

Tell your story

Communicate your brand values and really live them.

Be consistent

Maintain consistent messaging across all touchpoints.

The most promising aspect of this survey was the result that consumers would be willing to pay premiums for carbon credentials. Provided premiums can be established, this will provide a financial feedback loop to reward low emission beef producers and to purchase local carbon offset credits from the supply chain.

4.6 Supply chain engagement

The study revealed that the majority of emissions, and the greatest opportunity to reduce emissions and sequester carbon, arise at the farm scale. However, the market research has shown that engagement with customers and consumers seeking improved environmental credentials primarily occurs amongst brand owners and retailers. Achieving improvements in environmental credentials such as GHG emissions requires a whole-of-supply-chain approach to deliver communication and engagement from producers through to consumers and Government.

In bringing about change, there will be inevitable costs to production from emission reduction and carbon storage activities.

Emerging methane mitigation strategies using feed supplements such as red Asparagopisis or Bovaer are expected to add costs to feeding programs, though commercial costs have not yet been established. It may not be possible to mitigate emissions without increasing cost-of-production, and the supply chain must grapple with cost-sharing and potential increased prices at the retail shelf to achieve environmental outcomes.

In the case of carbon storage, both direct costs (such as the cost of tree planting) and indirect costs such as impact on asset values may occur. The potential impact on asset values is currently very unclear. In the case of small-scale tree planting there may be benefits to productivity from shade or control of other problems such as salinity or wind erosion. However, in the case of large-scale regeneration of grazing land to forest, long-term declines in asset value may occur because trade-offs are likely to emerge between carbon sequestration and stocking rate, leading to lower capacity for these areas to produce beef. Again, cost-sharing and potential increases in the price of beef must be determined and managed for transformational change to occur.

Costs will also arise from compliance, to implement meaningful emission estimation and potentially carbon sequestration offsets across a large number of businesses. Cost minimization and a mechanism to fund carbon neutrality throughout the supply chain will be essential to drive uptake amongst producers and across industry.

As previously noted, new approaches to achieving carbon sequestration in grazing landscapes, while minimizing the risk to production capacity, are required. This needs to extend beyond the limitations of the current suite of ERF methods available. New approaches that reduce compliance burden are also needed, and initiatives such as the Environmental Plantings pilot are beneficial.

Considering these above needs, a step-change will be required in at least three areas to stimulate engagement in the producer base: simple and robust systems are needed for compliance; new, robust and effective methods are needed to expand the options for sequestration and reduce compliance costs; and cost-sharing models will be needed that incorporate a broad range of stakeholders across the supply chain. In particular, consumers and Government will be critical to building a sustainable model to fund carbon neutral beef into the future.

5. Conclusion

5.1 Key Findings

This study presents the first large scale baselining and emission reduction plan for a beef supply chain in Australia, to the author's knowledge. The study provided a clear view of the emissions profiles and emission reduction opportunities of a large-scale supply chain in Western Australia, with relevance to the broader Australian beef industry; particularly relating to current market insights and the program of work required through research, extension and development to achieve current industry emissions goals.

Key findings included:

Emission reduction and sequestration:

- Beef herd management improvements, such as improved weaning and growth rates, reduced mortality, and expansion of grain feeding are expected to achieve ongoing, incremental improvements in the emissions intensity profile of the supply chain, in this case leading to an improvement of 5.3% to overall supply chain emissions intensity. Opportunities are greatest for the northern industry, where cattle performance is more constrained and the opportunities for improvement are greater. This will be necessary to reduce emissions, particularly if the industry is to expand throughput by drawing more cattle from the north of the state.
- Methane mitigating feed additives have the potential to deliver significant methane emission reductions at various points of the supply chain, such as during grain finishing. Feed additives were assumed to provide benefits within feeding facilities from 2024 and to grazing operations from 2027. Supply chain emissions mitigation from feed additives was forecast to improve incrementally throughout the decade, achieving a 9% improvement in emissions intensity for the supply chain by 2030. Together with beef herd management, combined emission mitigations were forecast to be 14.3% for the supply chain emissions intensity by 2030.
- Considering the central role of methane and the challenges in substantially reducing methane in the supply chain to 2030, there would be merit in further examining what is required to assess and potentially accredit so called "Climate Neutral" supply chains, which may apply different metrics for assessing the impact of methane.
- This study identified that carbon neutrality would require a significant amount of sequestration in soil and vegetation. Significant effort will need to be invested in establishing the practices and measurement approaches needed to achieve these outcomes and measure the impact across the supply chain. Specifically:
    - Lower-cost measurement is a critical need for assessing soil carbon change. Current ERF soil carbon projects are very expensive, and costs are greatest when measuring small change over large areas such as in pastoral zones. This is a critical gap for the beef industry.
    - Vegetation ERF methods are suited to large projects. In a supply chain context, many small projects are required to quantify vegetation carbon sequestration. Costs are

    anticipated to be a barrier to widespread adoption. Other systems with lower compliance costs are required that can reliably quantify vegetation carbon sequestration in small areas on large numbers of farms.
    - New strategies are required to quantify vegetation sequestration in areas that currently don't fit within the ERF methods. For example, sequestration occurring in forest that can't be cleared for regulatory reasons can't be included in the ERF, but there may be other mechanisms that can enable beef supply chains to quantify and claim the sequestration from these sources.

Market engagement:

- The market study revealed that consumers have a general understanding of environmental sustainability, however understanding of carbon neutrality in relation to the beef industry is lower. A strong market of environmentally-conscious 'Early Adopters' was identified, with a proportion of the public willing to pay a price premium for carbon neutral beef products. It was discovered that people care deeply about sustainability and are changing their behaviours to be more eco-conscious, however carbon neutrality is not currently well understood and has limited market presence. As a result, actions to deliver watertight and consistent communication and messaging to consumers and industry are required, including at brand level.

Supply chain engagement:

- This project revealed that the majority of emissions and the greatest opportunities to reduce emissions or sequester carbon arise at the farm scale. However, engagement with customers and consumers seeking better environmental credentials primarily happens amongst brand owners and retailers. Improving and communicating environmental credentials requires an integrated, whole-of-supply-chain approach with high engagement with producers through to consumers and Government. To bring transformative change, two key needs have emerged:
    - Firstly, systems will need to be implemented to enable transfer of information around the carbon credentials of livestock and beef throughout the supply chain. This needs to be done in a robust and auditable way, and cost sharing will be required across the supply chain.
    - Secondly, cost minimisation and a mechanism to fund carbon neutrality is needed throughout the supply chain. Consumers and Government will be critical stakeholders to engage to build a suitable model to fund carbon neutral beef into the future.

The above findings highlight the need to develop an adoption program in the supply chain with a mid to long term view (at least to 2030) to address the many and complex needs that emerge in bringing transformational change across the whole supply chain.

6. Future research and recommendations

6.1 Action plan for supply chain to achieve carbon neutrality by 2030

The role of HRG in investigating and demonstrating opportunities to reduce net emissions and improve productivity across WA industry will be increasingly important as industries and governments move towards carbon neutrality. Significant research, development and industry extension programs are required to realise the potential identified here. This will be strategically important for enabling producers to deliver a path towards industry goals through practical, implementable action on their farms.

Recommendations are provided in Table 12 to progress from the results presented here.

Table 12. Priority actions to achieve carbon neutrality by 2030 for the supply chain

Action	Timeframe
Baseline carbon footprint and establish emission reduction and carbon storage options with suppliers and be able to report this into market claims.	2022-2030. Intensive focus 2022-2024.
Provide demonstration and extension programs to producers to enable best practice uptake, including using HRG operations.	Launch 2022. Deliver programs from 2022-2030. Intensive focus 2022-2024.
Establish a cost-effective program for suppliers and Harvey Beef for carbon neutral beef.	2022-2030.
Undertake gaps analysis and create a feedback loop to research.	Intensive focus 2022-2023. Annual feedback loop 2022-2030.
Implement supply chain wide enteric methane mitigation in feedlots via supplement usage.	2023-2027
Implement mitigation strategies via improved herd management in northern regions.	2022-2030
Develop and implement soil carbon sequestration projects at scale throughout the supply chain.	2022 onwards
Implement vegetation projects – HIR and tree planting at scale throughout the supply chain.	Pilot and demonstrate from 2022. Implement broadly from 2025-26.
Implement enteric methane mitigation strategies in grazing herd at scale throughout the supply chain via supplement usage.	2028-30

6.2 Other recommendations

This study found interesting results relevant to the broader WA beef industry, but gaps remain. The report has shown important macro indicators towards major emissions production across the supply chain, but acknowledges important geographic characteristics contribute greatly to regional differences Particularly, the results presented here for the Pilbara and more so the Kimberley should be viewed with caution, as they reflect a supply chain delivering processing cattle out of these regions which is not representative (particularly in the Kimberley) because many cattle are sold to live export markets from these regions.

In the WA context, the WA Government is in the process of establishing net emission reduction pathways and targets for the agriculture sector at the present time. Ambitious action is central to meeting stakeholder expectations and underpinning the market, and assistance will be required to facilitate change in the most emission exposed sectors.

More broadly, the red meat and livestock industry, supported by MLA, has established an ambitious goal to be carbon neutral by 2030. At present, companies are developing their strategies to achieve this, but few have advanced to setting corresponding goals throughout their supply chains. HRG are pioneering an actionable plan to reduce net emissions and implementing this through the supply chain across hundreds more businesses that supply cattle. This is a strategically important test case for a supply chain.

A program is required to bring this proportion of the agricultural sector to carbon neutral by 2030, as producers tend to supply both HRG and other markets. Providing leadership across a broad spectrum of the industry will stimulate action that extends well beyond the direct supply chain.

The scale of HRG's reach across the beef supply chain in Western Australia provides a unique opportunity to lead a noticeable improvement in the sustainable and profitable production of Australian beef. Extension materials, demonstration sites and case studies that show real action in reducing emissions on farm will be necessary to help industry meet is carbon neutral targets.

Market research has found that consumer sentiment is favourable towards environmentally sustainable products and can attract a price premium at point of sale. As a result, it is anticipated that delivering improved carbon credentials across the WA beef industry will lead to improved perceptions of the environmental sustainability credentials of WA beef and enable an increase in the value of beef moving forward.

There is a knowledge gap around the current contribution to the GHG balance of WA farms from tree planting, revegetation, and soil carbon flux. Considering the quantum of the emissions and sequestration, further work is needed at the state level to quantify these and attribute them more accurately to sheep, cattle and other land uses.

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3-NOP	3-nitrooxypropanol
ABARES	Australian Bureau of Agricultural and Resource Economics
ADG	Average daily gain
CN30	The red meat and livestock industry’s goal to be carbon neutral by 2030
DMI	Dry matter intake
DMD	Dry matter digestibility
DSE	Dry Sheep Equivalent
ERF	Emission Reduction Fund
GHG	Greenhouse gas
GWP	Global Warming Potential ($\text{GWP}_{100\text{ is}}$ the GWP over 100 years)
HRG	Harvest Road Group
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt-hours
LCA	Life Cycle Assessment
LW	Liveweight
LWG	Liveweight gain
MAP	Monoammonium phosphate
MLA	Meat & Livestock Australia
NIR	National Inventory Report
WA	Western Australia

Appendix

Glossary