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Options for mitigating greenhouse gas emissions for the Australian Vegetable Industry

Discussion paper 6.

Vegetable Industry Carbon Footprint Scoping Study – Discussion Papers & Workshop

HAL Project VGO8107

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Purpose of the Report *–*

A Carbon Footprinting Workshop for the Vegetable industry will be held October 2008 (VG08107: Vegetable Industry Carbon Footprint Scoping Study - Discussion Papers and Workshop). To ensure the carbon workshop is successful in gaining agreement on the industry needs and future investment priorities for carbon footprinting, six (6) discussion papers have been commissioned by HAL to address a number of key questions that will be the focus of debate at the workshop. This report is one of these Discussion Papers, which will be distributed prior to the workshop.

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Contents

Executive Summary

This report discusses the future opportunities for the Australian vegetable industry to reduce its carbon footprint. It has been written as part of a series of six discussion papers for a workshop that will set future directions for R, D & E on greenhouse gas emissions from the vegetable industry.

Currently there are efforts to quantify the carbon footprint of the Vegetable industry, however the focus must also turn to identifying actions available to minimises greenhouse gas (GHG) emissions and reduce the carbon footprint of the Vegetable industry.

The aim of this report is to i) identify practical methods by which Australian vegetable growers can manipulate and minimise their carbon footprint and ii) identify potential R, D & E needs required before vegetable growers can implement these changes.

This report identifies considerable opportunity to reduce energy use and greenhouse gas emissions and thus improve the carbon footprint of the vegetable industry. The first step is to identify where the major emissions are occurring, and which of these can practically and economically be changed.

Reducing upstream emissions involves growers exercising choice over the type of external inputs used in production. Growers need to choose products with low embodied energy and emissions. While this is difficult to determine at the moment, with increasing labelling regulation at all levels, identification of such products will become easier in the future.

Both the quantity of direct on-farm emissions and opportunities to reduce them will vary by farm, location, climate, crops grown, input sources, and markets sold to. Individual farms need a system of auditing GHG emissions in order to identify where their particular contributions are coming from and what potential there is to mitigate.

On farm GHG mitigation options mainly relate to:

- Reducing the quantity of inputs arriving on the farm
- Improving efficiency of input use on farm
- Reducing GHG emissions from soil through improved fertiliser, irrigation and organic matter input management, and reducing tillage

Other important considerations when identifying mitigation of on-farm emissions are:

- The effect mitigation options have on productivity and profitability
- The effect mitigation options have on production costs
- The effect mitigation options have on product quality and product waste (eg. packaging increases GHG emissions, but prolongs shelf life and reduces waste)
- Downstream effects, reducing emissions at one point in the production process may increase emissions downstream, or visa versa (eg. some fertiliser formulations may have lower emissions during production, but increase nitrous oxide emissions on farm)

Opportunities to influence the downstream emissions are limited, and mainly relate to the transport of produce to market. Mitigation options include employing energy efficient modes of transport and the use of low GHG emitting fuel types.

The R, D & E needs identified in this discussion paper generally fall into three types:

i) Research to measure the GHG emissions under current or improved management practices to demonstrate the vegetable industries emissions.

ii) Benchmarking of current industry practice, in relation to practices that influence GHG emissions.

iii) Packaging of information on the consequences of different management techniques or purchasing options on GHG emissions, and the BMP's for reduced GHG emissions, into easily understandable fact sheets for the vegetable industry.

Through this paper we have effectively conducted a broad review of the types of GHG mitigation options there are available to the Australian vegetable industry, but have not given due consideration to practical and economic implications any changes. The impact that each option has on productivity and profitability must be considered. Growers must remain competitive and profitable. Potentially many of these GHG mitigation options could improve production efficiency and increase productivity, and may give farmers a competitive edge. These options are more likely to be adopted than options that simply reduce GHG's or reduce GHG's at a cost to producers.

Additionally, these and other mitigation options need to be considered in the context of a complete Australian vegetable industry carbon footprint in order to priorities the various options by magnitude of GHG abatement. Following this, a cost-benefit analysis for each mitigation option is required to determine the CO_2 –e emission saving per dollar spent on mitigation. Some changes might be costly and only result in small reductions in GHGs, while others might cost much less and result in big reductions.

Further investigation is required into many mitigation options as there is still debate about degree of GHG abatement when the full carbon footprint of each input is accounted for.

Introduction

This report discusses the future opportunities for the Australian vegetable industry to reduce its carbon footprint. It has been written as part of a series of six discussion papers for a workshop that will set future directions for R, D & E on greenhouse gas emissions from the vegetable industry.

There is increasing confidence about the causes of climate change and the likelihood that climate change will occur [1], however, a complete understanding of the likely consequences for the Australian vegetable industry are far from clear. Global warming is likely to throw up numerous challenges for the Australian vegetable industry. These are likely to include; market pressures, with consumers demanding 'green' produce, and restricted access to markets if products do not have good climate credentials or cannot verify them [1]; production pressures, caused by increased climate variability and reduced resource availability; and cost pressures associated with reduced resource availability and the introduction of carbon taxes.

Currently there are efforts to quantify the carbon footprint of the Vegetable industry, however the focus must also turn to identifying actions available to minimises green house gas (GHG) emissions and reduce the carbon footprint of the Vegetable industry.

The aim of this report is to i) identify practical methods by which Australian vegetable growers can manipulate and minimise their carbon footprint and ii) identify potential R, D & E needs required before vegetable growers can implement these changes.

This report divides mitigation practices into three sections: i) Pre-farm (upstream-indirect), ii) On-farm (direct), and iii) Post-farm (downstream-indirect). A conventional carbon footprint divides GHG emissions into these same categories, however when considering mitigation mechanisms the actual mitigation practice may fall into a different category to the emission itself. As an example, GHG emissions associated with the production of inputs prior to reaching the farm gate are considered upstream emissions in a carbon footprint. However, these emissions can be mitigated in two ways: 1) by using less of that input on farm (direct on-farm mitigation); or 2) by choosing a supplier that uses processes with lower GHG emissions (indirect mitigation). For this reason, 'headings' for mitigation options in this paper may not align directly with headings in discussion paper 4, which outlines the actual carbon footprint of the vegetable industry.

I. Pre-farm (upstream) greenhouse gas mitigation options

Pre-farm greenhouse gas (GHG) emissions are those produced through the production of materials or inputs that go towards on farm production. These are sometimes referred to as 'upstream' or 'indirect' GHG emission. Although growers can not directly control these emissions, they can subject some control though choice of suppliers that produce materials and inputs with the lowest possible GHG emissions.

'Embodied energy' is the energy consumed by all of the processes associated with the production of a product, from the mining and processing of natural resources to manufacturing, transport and product delivery [2]. Embodied energy does not include the operation and disposal of the material, this would be considered a 'life-cycle' approach. Embodied energy is the 'upstream' or 'front-end' component of the lifecycle impact of a product.

Similar to embodied energy, 'embodied emissions' are all of the GHG emissions associated with the production of a product. CO_2 emissions are highly correlated with the energy consumed in manufacturing. On average, 0.098 tonnes of CO_2 are produced per gigajoule of embodied energy [2].

Estimates of embodied energy and emissions provide a useful tool for identifying 'upstream' emissions contributing to the carbon footprint of the vegetable industry, and a means of comparing alternative materials and inputs for use in the industry to minimise the carbon footprint.

Fertiliser production

Key opportunities to reduce GHG emissions:

- *Choose fertiliser formulations with lower GHG emission during production*
- *Choose fertilisers made from modern, 'clean' processes*
- *Consider GHG emissions on a 'per tonne of element' basis, not just 'per tonne of product'*
- *Choose fertilisers that have raw materials with short travel distances*
- *Consider both upstream and on-farm GHG emissions when selecting the most appropriate fertiliser.*

GHG emitted during fertiliser production are attributable to vegetable production as indirect GHG emissions. Greenhouse gases are emitted during the production of most fertiliser products, and as fertiliser is a considerable input in vegetable production systems it is an important source of GHG emissions. Reducing the quantity of on-farm fertiliser used is covered in direct mitigation options.

The quantity of upstream GHG emitted varies dramatically depending on fertiliser formulations. Figure 1 shows the average GHG emissions (tCO_2–e/ t product) produced from fertiliser production in Europe for various formulations. The error bars for each formulation (Figure 1) show the variability in GHG emissions associated with different fertiliser production methods. Generally more modern fertiliser production techniques cause lower GHG emissions. Some methods of fertiliser production result in the production of energy and therefore actually result in a net carbon sink.

However, different fertiliser formulations contain different quantities of base elements (Nitrogen, Phosphorus, Potassium etc). When GHG emissions are calculated on a 'per tonne of element' basis the relative standing of each formulation changes. Figure 2 shows GHG emissions for the same group of fertiliser formulations however the GHG emissions are in terms of 'tonne CO_2-e per tonne of nitrogen'. Although Ammonia was shown to have relatively high GHG emissions on the basis of tCO_2-e/t product, because it has a much higher nitrogen concentration, GHG emissions are relatively low on a tCO_2-e/t nitrogen basis [3]. This is important because less of this product need be applied to achieve the same nitrogen application rate. Additionally, formulation with higher elemental concentrations required a smaller quantity of product to be transported from the fertiliser manufacturer to farm, reducing the upstream GHG emissions further.

Further investigation is required into predominant fertiliser production processes in Australia and the associated GHG emissions.

It is important that the upstream GHG emissions are not the only consideration used for fertiliser selection. This is because in certain conditions some fertiliser formulations are more likely to result in nitrous oxide emissions after application. This could potentially counteract any benefits made by selecting a formulation with lower GHG emission during production.

Vegetable growers can therefore potentially alter GHG emissions attributable to their production systems by changing fertiliser formulation used and/or purchasing fertiliser from produces using newer and cleaner production methods. However, the upstream emissions must be considered in combination with the on farm emissions to arrive at the best fertiliser selection.

R, D & E needs:

- Review of GHG emissions from fertiliser production methods used in Australia.
- Review of GHG emissions associated with the main fertiliser products used in Australia, and the sources of raw materials.

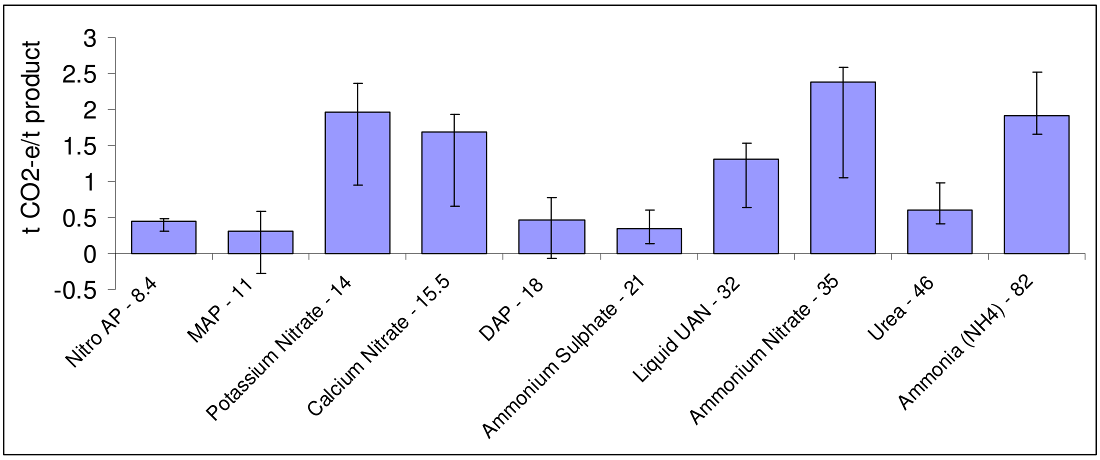

Figure 1. Average GHG emissions (tCO_2-e/t product) caused by the production of various fertiliser formulations in Europe. (Taken from [3])

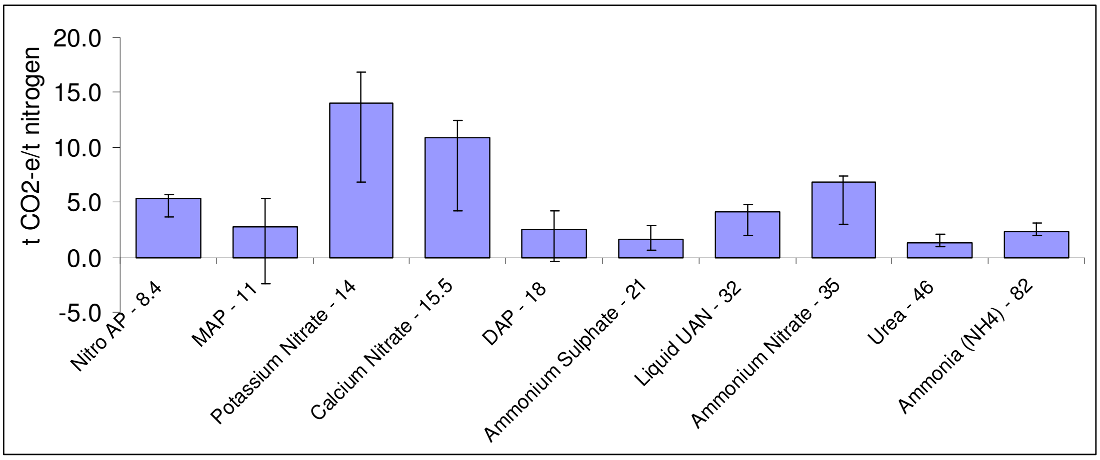

Figure 2. Average GHG emissions (tCO_2-e/t nitrogen) caused by the production of various fertiliser formulations in Europe. (Taken from [3])

Electricity generation

Key opportunities to reduce GHG emissions:

» *Choose to purchase 'Green' electricity – can reduce GHG emissions from electricity consumption to zero*

Electricity is produced using a range of different technologies each of which have different carbon emissions. These emissions are released at the point of electricity generation and not at the point of consumption and are therefore considered indirect emissions. However, because of the importance of reporting on electricity emissions they are given a special category, referred to as Stage 2 emissions. Consumption of electricity is a major contributor of indirect GHG emission for the vegetable industry as it is used to run pumps, processing plants and for cooling and refrigeration of produce. Although electricity is an indirect emission, options available to reduce electricity consumption have been included under the 'direct mitigation options' section of this report.

Consumers can choose the source of their electricity through the purchase of 'Green' electricity. Green electricity is sourced from sun, wind or hydro power, and is produced with minimal GHG emissions (see Discussion Paper 4). The purchase of accredited renewable energy does not mean your electricity will come directly from a renewable source to your property, rather the equivalent amount of new renewable energy will be added to the electricity grid on your behalf every year so you will be responsible for a reduction in greenhouse gas emissions.

A business can choose the proportion of electricity it wants to source from green energy. The costs vary, but for businesses current costs are around 1 cent/kWh for 10% accredited green power, or 5 cents/kWh for 100% accredited green power [4].

Assuming an average vegetable farm uses 3900 MJ/ha/year of electricity for pumping irrigation water (bases on New Zealand electricity use figures, [5]), switching to 100% green electricity would approximately cost an extra $55/ha/yr, saving 1 t CO_2-e/ha/yr and increasing electricity costs by 26%. Switching to 10% green electricity would cost an extra $11/ha/yr, saving 0.1 t CO_2-e/ha/yr and increasing electricity costs by 5% (assuming coal derive electricity produces 250 g CO_2e/MJ [6] and standard peak electricity costs 18.95 cents/kWh).

An alternative option is for farm businesses to generate their own electricity using wind or solar power. However, it is unlikely that for the foreseeable future this technology will be more cost effective than purchasing Green energy.

R, D & E needs:

- Provide the industry with information on the cost of power substitution using Green energy and on farm solar generation.

Fuel production

Key opportunities to reduce GHG emissions:

» *Use fuel sources with low GHG emissions during production.*

» *Also consider GHG emission during combustion (an on-farm emission), which can vary greatly for different full types.*

Different fuel sources cause different quantities of GHG emission during production. This is shown for a range of fuel types in Figure 3, where the blue portion of each bar shows the GHG emissions (g/km CO_2-equivalents) created during fuel production. A grower can therefore potentially reduce GHG emission by choosing a fuel source that has a lower emissions factor for its production.

However, as with fertilisers, growers also need to take into account the GHG emission produced when using a fuel, which also varies for different fuel types. The GHG emissions from fuel combustion are represented by the maroon potion of each bar in Figure 3. It can be seen that, for example, while biodiesel has a relatively large GHG contribution associated with its production, there are almost no GHG emissions associated with the combustion of biodiesel [7].

R, D & E needs:

- Provide the industry with information on the feasibility and cost of fuel substitution using biodiesel.

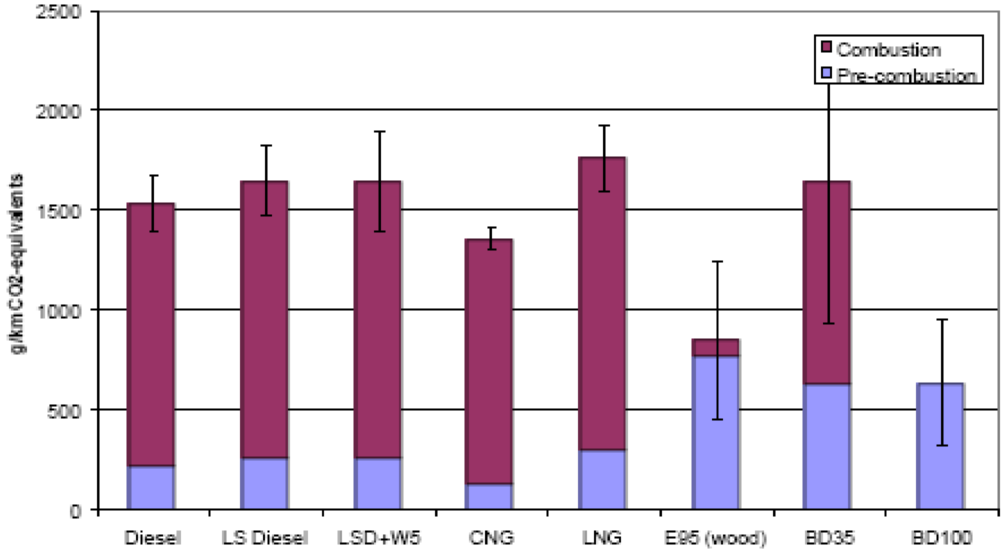

Figure 3. Total greenhouse gas emissions (CO2-equivalents) in g/km form heavy vehicles for a range of fuel types. (LS Diesel = Low Sulfur Diesel, LSD + W5 = Low Sulfur Diesel + 5% Waste Oil, CNG = Compressed Natural Gas, LNG = Liquefied Natural Gas, E95 = 95% Ethanol made from wood, BD35 = 35% Biodiesel, BD100 = 100% Biodiesel) [7]

Manufacture of packaging

Key opportunities to reduce GHG emissions:

» *Reduce the quantity of packing material*

» *Choose packaging made from material types with low embodied energy*

» *Choose packaging made by manufacturing processes that result in low embodied energy*

» *Choose packaging made from recycled material*

Energy is used in the production of raw material (aluminium, plastic, glass etc), as well as in the manufacturing of that raw material into a useful products (e.g. plastic packaging). The embodied energy and emissions varies for different raw materials (Table 1). Choosing packaging made from raw materials with low embodied energy, and low energy use during the manufacturing process will reduce the carbon footprint of the vegetable industry.

Using recycled material can also significantly reduce the embodied energy of a product. Although manufacturing with recycled materials can involve transporting, cleaning, and sorting the recycled material, this often requires far less energy than manufacturing from a virgin resource that must be extracted and refined before use. It should be noted that GHG savings made by recycling of materials for reprocessing varies considerably, with savings up to 95% for aluminium but only 20% for glass [8]. Reprocessing of recycled material can even use more energy, particularly if long transport distances are involved.

R, D & E needs:

- Produce a study of the GHG emissions associated with different packaging systems used in the vegetable industry, and provide information on how lower C-footprint packaging systems have been developed internationally.

Table 1. Embodied energy (GJ/t) of various new and recycled packaging materials [8]

	Embodied Energy (MJ/kg)	
Material	**New**	**Recycled**
Steel	32.0	10.1
Aluminium	191.0	8.1
Plastics	98.0	12.0
ABS	111.0	
high density polyethelene (HDPE)	103.0	
low density polyethelene (LDPE)	103.0	
polyester	53.7	
polypropylene	64.0	
polystyrene, expanded	117.0	
polyurethane	74.0	
PVC	70.0	
Glass	15.6	12.5
Paper	36.4	23.4

Construction of buildings and building materials

Key opportunities to reduce GHG emissions:

» *Construct infrastructure with materials of low embodied energy*

As with packaging, all building materials have embodied energy and GHG emissions associated with their manufacture, however the quantity varies greatly for different materials (Figure 4). To reduce the carbon footprint of the vegetable industry construction using materials with low embodied energy and GHG emissions should be used where possible.

Although rebuilding farm infrastructure with low-embodied energy materials is not likely to be cost or energy efficient, doing so when extending or upgrade infrastructure is likely to be beneficial.

Choosing the most suitable low-emission and low-energy materials requires consideration of both material strength and life. For example, steel has more embodied energy than concrete per weight, however it is much stronger and far less of it is required for similar functions. Also aluminium has a very high embodied energy compared to timber, but for some uses in a building aluminium may have a much longer lifespan.

R, D & E needs:

- Compare data on the relative GHG emissions associated with different building materials based on a substitution, not weight, basis, and information on new materials being developed.

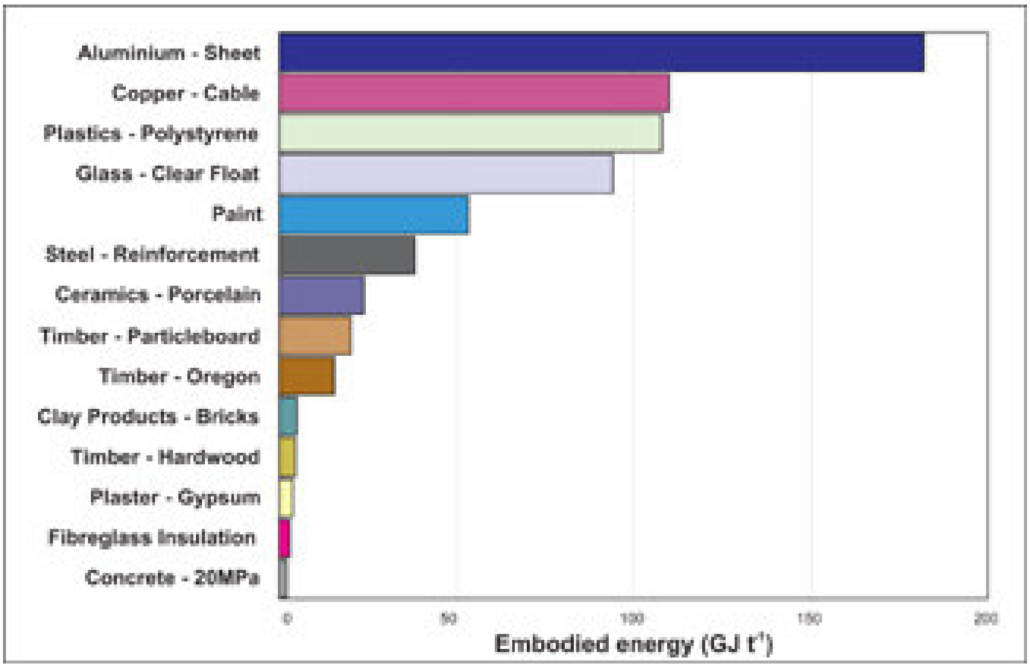

Figure 4. Embodied energy (GJ/t) of various building materials [2]

Manufacture of machinery

Key opportunities to reduce GHG emissions:

» *Purchase machinery with low-embodied energy and GHG emissions*

» *Purchase machinery of an optimum size for the scale of the operation*

» *Minimise purchase of equipment, but keeping in mind that old machinery may be inefficient.*

» *Where possible purchase one multipurpose machine, rather than multiple single-purpose machines*

All machinery has embodied energy and emissions associated with the production of the materials and manufacture of the machine itself. Generally the larger the machine the greater the embodied emissions [9].

Vegetable growers can reduce their carbon footprint by purchasing machinery that suits the size of the operation. A grower's machinery inventory can potentially be reduced by purchasing machinery suitable for performing a number of operations, rather than single purpose machinery.

R, D & E needs:

- Investigate possibilities for multi-purpose equipment (both existing and future development)
- Engage machinery manufacturers in a dialog with the industry about the potential for more multipurpose equipment and attachments.

Table 2. Energy coefficients, carbon dioxide emission factors and assumed working life of motor vehicles and farm implements. Emissions factors include the embodied energy of the raw materials, the fabrication energy, an allowance for repairs and maintenance, and international freight [9].

Capital Item	Energy Coefficient	Carbon Dioxide Emission Factor	Working Life (years)
Tractors	160 MJ/kg	12.8 kg CO_2/kg	15
Heavy Trucks	160 MJ/kg	12.8 kg CO_2/kg	15
Light Trucks/Utilities	160 MJ/kg	12.8 kg CO_2/kg	15
Motor Bikes	160 MJ/kg	12.8 kg CO_2/kg	10
Farm Implements	80 MJ/kg	7.2 kg CO_2/kg	20

Transport of inputs to farm

Key opportunities to reduce GHG emissions:

» *Use energy efficient and low GHG emitting modes of transport*

» *Use the most energy efficient low GHG emitting fuels in transport*

» *Maximise volume of product transported per trip*

» *Reduced the distance inputs are transported*

» *Ensure back loading is used*

The mode of transport used to move goods can have a considerable impact on GHG emissions. Generally truck or rail freight transportation is the most efficient (Table 3). There is still some debate over which of these has lower emissions, but case specific circumstances (eg. proximity of rail system) are likely to determine which is more efficient. Shipping is the most energy efficient means of intercontinental transport and air freight is the least efficient freight transport mode.

The type of fuel used in transport can also significantly influences GHG emissions. Renewable fuels such as bio-diesel (refined from vegetable oil) and ethanol generally contribute least GHG emissions when used for road transport [10]. New hybrid-electric options are likely to be very low GHG emitters, especially if Green electricity is used. Various forms of diesel are the heaviest contributors, while liquid petroleum gas (LPG) and natural gas fit somewhere in between [10].

Sourcing inputs locally reduces distance transported and can dramatically reduce greenhouse gas emissions, this is concept embodied in Food Miles (Table 3). Ensuring containers are loaded to capacity, and have a return load will reduced greenhouse emissions per unit of product transported.

R, D & E needs:

- Engage the transport industry in a dialog about the potential for lower GHG emissions systems. Produce a C-footprint rating of potential transport companies to encourage competition and practice change.

Table 3. CO_2 emissions associated with different freight transport modes [11]

Transport mode and transport distance	g CO_2/kg
Short distance (400 km)	
Truck	54.66
Electric freight train	69.15
Inland vessel	
Bulk	29.77
Non-bulk	79.72
Continental transport	
Truck	204.98
Electric freight train	259.32
Freight aircraft	2149.20
Sea vessel	
Bulk	599.82
Non-bulk	1605.98
Intercontinental transport	
Freight aircraft	8509.68
Sea vessel	
Bulk	2399.29
Non Bulk	6423.90

Other pre-farm GHG mitigation opportunities

There are a number of other inputs that are likely to contribute upstream emission to the carbon footprint of the vegetable industry. Some of these inputs are likely to have quite complex carbon footprints of their own, but have not yet been properly investigated. Understanding the carbon footprint of each of these inputs is essential to identifying all opportunities to minimise GHG emissions. Inputs not yet investigated include:

- Agro-chemicals (herbicides, fungicides, insecticides)
- Planting stock (seedlings)
- Organic amendments (compost, biochar, poultry litter, animal manures)

II. On-farm (direct) greenhouse gas mitigation options

On-farm GHG emissions are the gases directly released during the activities and processes on-farm, including GHG emissions from fuel use and soils, such as from fertiliser applications. These emissions are directly attributable to on farm management practices and therefore can be controlled and minimised directly by growers.

Some upstream GHG emitting activities, such as electricity production or fuel production, have on-farm mitigation options. These options reduce the quantity of the upstream activity required, but do not affect the emissions per unit output from that upstream activity.

Irrigation

Key opportunities to reduce GHG emissions:

- » *Distribute water efficiently by installing and maintaining an efficient irrigation system*
- » *Use steps to minimise the amount of water required to be pumped*
- » *Maximise production efficiency of water that is applied*

Pumping of irrigation water is the second largest user of on-farm energy in the New Zealand vegetable industry [5], constituting 37% of on-farm energy use. If on-farm fuel is used for pumping, mechanisms available to reduce GHG emissions come from substituting with lower GHG emissions fuels such as solar or wind energy. Other reductions revolve around minimising the amount of energy required to move water by installing and maintaining efficient irrigation systems, and minimising the amount of water that needs to be pumped by maximising the production efficiency of water that is used.

An on-farming monitoring project in New Zealand demonstrated a 15% electricity saving by farms implementing the types of strategies described below [12].

Improve irrigation management by minimising the amount of water that needs to be applied. Strategies include:

- Acquire the knowledge required to systematically schedule irrigation
  - Know crop water requirements
  - Know soil characteristics (soil water holding capacity, salinity)
  - Know rate of water loss (evapotranspiration)
- Meter applied water
  - Accurately know and track how much water has been applied
- Monitor rainfall
  - Combine rainfall data in irrigation scheduling
- Monitor soil moisture
  - Ensure water is applied at appropriate times and appropriate rates

- Avoid irrigating in windy conditions
- Irrigate at night where possible
- Irrigate when required, but on a 'little but often basis'

Installing and maintaining an efficient system will minimise the energy needed to pump required water. Strategies include:

- Maximise irrigation uniformity by using the optimum nozzle type, sprinkler configuration, operating pressure. Improving irrigation uniformity reduces the mean application depth applied to ensure an area is fully irrigated. For example improving distribution uniformity from 70% to 90% will reduce water and energy use by 30%, or alternatively allow 30% more area to be irrigated [5].
- System auditing will shows inefficiencies in the design and/or operation of the system
- System maintenance
    - changing worn sprinklers and nozzles will improve system efficiency
    - fix leaks and blockages
- System design
    - Minimise pipe bends and sharp corners which result in pressure loss
    - Over-sized pumps results in excessive pressure within the irrigation system pipes which can require the gate valves to be partially closed. This means high electricity usage for the volume of water pumped.
- Use energy efficient pumps and motors
- Use appropriately sized pumps and pipes
- Match irrigator number and size to pump capacity
- Use solar pumps rather than diesel pumps

R, D & E needs:

- Undertake an inventory of the range of irrigation practices used in the vegetable industry, and benchmark the best practices against the others growers and the results of the NZ study, to estimate the potential level of industry reduction in C-footprint.
- Undertake research to better understand crop water requirements and irrigation scheduling tools for the vegetable industry.

Nitrogen fertiliser use - Nitrous oxide emissions from soil

Key opportunities to reduce GHG emissions:

» *Improve nitrogen use efficiency of applied nitrogen*

» *Use management practices that match nitrogen supply to crop needs*

» *Create a soil environment unconducive to denitrification*

Nitrous oxide constitutes approximately 6% of total CO_2-e emissions from Australia [13]. Of the total national nitrous oxide emission, 18% result from the application of nitrogen fertilisers to agricultural soils and 22% result from soil disturbance in agriculture, constituting 1.1% and 1.3% of Australia's total CO_2-e emission, respectively.

While horticulture only represents a small proportion of land used for agriculture in Australia (vegetable = 0.034%, horticulture = 0.13% [14]), horticulture accounts for approximately 12% of nitrogen fertiliser use in Australian agriculture [13], exemplifying the high rates of nitrogen fertiliser used in the horticultural industry. High nitrogen fertiliser application rates result in higher nitrous oxide emission [13], therefore the vegetable industry potentially contributes a significant proportion of Australia's nitrous oxide emissions, with emissions likely to be relatively high on a 'per unit area' or 'per unit production' basis.

Soil mineral nitrogen (ammonium, nitrite and nitrate) content governs nitrogen supply to crops, but also governs the N supply to denitrifying microorganisms integral in the production of nitrous oxide from soil. Strategies aimed at reducing N_2O emissions from agricultural soils are based largely on better matching the supply of mineral nitrogen to the needs of the crop, both spatially and temporally. Management practices that improve plant uptake (efficiency) of applied nitrogen and/or reduce required application rates, lower the amount of mineral nitrogen available for denitrification.

Fertiliser management options that reduce N_2O emissions by improving applied nitrogen use efficiency include [13]:

- Apply fertiliser N at optimum rates by taking into account all N sources available to the crop/pasture from soil, and other N sources such as legume, manure or waste.
- Apply fertiliser N at the rate and time to meet crop needs, and when appropriate through split applications.
- Avoid fertiliser N application outside the crop-growing season. Avoid fallow periods if season or availability of irrigation permits.
- Guide nitrogen fertiliser applications rates by using crop monitoring, yield maps and soil tests.
- Apply other nutrients if required so that nutrients supply to crop/pasture is balanced and N utilisation is optimised.
- Avoid surface application, incorporate or band place so that fertiliser N losses are minimised and plant utilisation maximised.
- Monitor and adjust fertiliser application equipment to ensure precise application rate and position of fertiliser.
- Improve spatial fertiliser application through Global Positioning System/Geographical Information System, yield/growth monitors, remote sensing, plant logging, soil tests and precision farming.

- Fertiliser should be in a form (such as granulated) that can be applied evenly, conveniently and cost-effectively. In irrigated agricultural systems, application in sprinkler/drip irrigation may be an effective option.
- Fertiliser may be formulated with urease and/or nitrification inhibitors or physical coatings to match fertiliser N release to crop/pasture growth needs.
- Practice good crop management, disease control and soil management to optimise crop growth.
- Use non-legume cover crops to utilise the residual mineral N following N-fertilised crops.

Nitrous oxide release from the soil can also be minimised by ensuring that the soil environment (chemical, physical and biological properties) is not conducive to denitrification, and subsequent nitrous oxide release.

Such options include ([13]):

- Irrigation management – maintain oxygen supply/soil water content so that the waterfilled pore space is < 40% as this increases nitrification but reduces N_2O loss, waterfilled pore space > 90% increases N_2 losses.
- Improve oxygen diffusion in soil by eliminating any compacted layer.
- Readily available carbon-substrate supply may create ‘hot spots’ of microbial growth, and hence increases in N_2O emissions; restrict readily available C supply - examples are addition or incorporation of biomass of high carbon: nitrogen ratio such as non-legumes rather than legume biomass.
- Soil organic matter management to manipulate carbon substrate and oxygen/water supply.
- Soil pH and salinity (salinity and high pH enhance the N_2O emissions due to the persistence of nitrite); soil amendments such as application of gypsum or crop residues of high carbon: nitrogen ratio reduce N_2O emissions.
- Eliminate limitations of other nutrients such as phosphorus, potassium or zinc.
- Grow cover crops during periods to remove residual nitrate from the soil profile.
- The application of manures and organic amendments should be immediately incorporation to minimise direct N_2O emissions and secondary emissions from decomposition of volatilised ammonia.

R, D & E needs:

- Develop an inventory of fertiliser practices in the vegetable industry.
- Evaluate through a literature review and incubation studies the evidence of the role of soil carbon on reducing or increasing N_2O emissions. This is important because increasing soil carbon is an important objective of the vegetable industry.
- Undertake research using laboratory and field techniques to better quantify the soil GHG emissions from vegetable production.

Type of fuel used

Key opportunities to reduce GHG emissions:

» *Choose fuels with low GHG emission (eg. bioidiesel or ethanol)*

» *Combine with appropriate engine maintenance to ensure maximum efficiency of fuel type used*

» *Consider other pollution types (eg. particulate pollution) which may have other environmental or human health consequences*

The level and type of air pollution generated by machinery depends largely upon the engine condition and the type of fuel used (Figure 3). CSIRO [7] has evaluated GHG emissions from a range of alternative fuels. Although this research relates to non-agricultural heavy vehicles, it provides a useful insight into the likely GHG emissions associated with the use of alternative fuels in agricultural machinery.

In relation to greenhouse gas emissions, renewable fuels such as bio-diesel (refined from vegetable oil) and ethanol were found to contribute least, while liquid petroleum gas (LPG) and natural gas contribute significantly more. Various forms of diesel are the heaviest contributors. Good engine maintenance is important to ensure that whichever fuel is used, the lowest possible emission levels are achieved [10].

In relation to air pollution based on human health impacts, LPG and natural gas contribute least, followed by low and ultra-low-sulphur diesel and ethanol. Standard diesel and Bio-diesel are considered heavy polluters. Bio-diesel rated poorly because higher levels of particulate pollution are produced during its production and use.

R, D & E needs:

- No specific R, D & E needs identified.

Fuel efficiency

Key opportunities to reduce GHG emissions:

» *Match engine size to the task*

» *Maximise traction through load balancing and tyre settings*

» *Maintain the most efficient engine speed, according to the manufacturer's specifications*

» *Maintain machinery in good working order*

Fuel use was identified as one of the major costs and users of energy by a committee of vegetable growers on the Mornington peninsular [15]. Using machinery in an energy efficient manner can reduce fuel use and GHG emissions. An on-farming monitoring project in New Zealand demonstrated a 15% fuel saving by farmers moving to reduced tillage systems, undertaking a driver awareness and education course and better matching tractors and implements to tasks [12].

To achieve best fuel efficiency and thus reduced fuel consumption, vegetable growers should consider [12]:

- Improve tractor traction
    - Increase tyre size - decrease fuel consumption by up to 10%.
    - Use dual tyres - same benefit as fitting larger tyres
    - Crawler tractors - for cultivation, this can decrease fuel use by 20% compared with two wheel drive tractors due to the increased footprint and lower rolling resistance.
    - Four wheel drive tractors can achieve up to 15% fuel savings when compared to two wheel drive tractors under soft soil conditions. On hard surfaces there is very little difference.
    - Where close attention is paid to tyre size and correct ballasting, two-wheel drive could expect to reduce fuel consumption by up to 20% in many situations.
- Optimise tractor size
    - Providing tractors are correctly ballasted, tyred and loaded, specific fuel consumption will be relatively constant and independent of tractor size. Thus in heavy load applications such as primary and secondary cultivation, tractor size will have little influence on fuel consumption per hectare. Inefficiencies often occur where tractors are not loaded to operate within their most fuel efficient range. Correct loading is more difficult to achieve for large tractors when on light load applications such as mowing or spraying. For example, a 50 kW tractor used to power an 8 metre boom sprayer and pump would consume approximately 1.5 litres of fuel/ha, whereas a 30 kW tractor on the same job, would require just 1.0 litre/ha.
- Keep and monitor fuel consumption records
    - Very few growers keep accurate tractor fuel consumption records which are essential for monitoring performance.
- Use optimum engine speed and gear selection
    - For maximum efficiency, tractor power should closely match implement demand to ensure the engine is working at or near maximum power. However, where only part engine power is required significant fuel savings are possible by selecting a higher gear and lower engine speed. This is where the phrase “change up – throttle back” comes from. Use of this technique could achieve fuel savings of up to 20%. A grower can achieve fuel savings of 10-15% during rotary cultivation by changing the gear selection on the cultivator and throttling back.
- Maximise traction efficiency
    - Traction efficiency involves a balance between wheel slip and rolling resistance. Too much wheel slip is a result of the tractor being too light, and will use excessive fuel. On the other hand

minimal wheel slip indicates excessive ballast. An understanding of the principles of wheel slip and ballast would lead to significant fuel savings. The optimum wheel slip for four wheel drive tractors in cultivated soil is between 8-12%, in uncultivated soil it lowers to 6-10%.

- Use hydraulics
    - The use of draught control or pressure control to transfer weight from the implement to the tractor is the most efficient means of adding weight to a tractor. Fuel savings in the order of 30% have been recorded when comparing draught operated implements with depth wheel controlled implements.
- Use optimum tyre inflation pressure
    - In soft conditions lower tyre pressures (e.g. 80 kPa) give increased contact area, less soil compaction, reduced rolling resistance and hence increased efficiency. On hard surfaces or for road work, inflation pressures should be increased (e.g. 150 kPa) to reduce tyre wear and rolling resistance. The use of lower pressures on soft ground can give fuel savings of up to 5%.
- Manage tractor idling
    - Idling for more than 20 seconds is wasteful as "start-up" fuel is usually equivalent to no more than 15 seconds use at idle. If the engine is turbo charged then consideration must be given to letting the engine slowly cool when determining the minimum and maximum idling time.

R, D & E needs:

- Produce information fact sheet for the industry on fuel saving techniques.
- Undertake a benchmarking project of fuel use in vegetable production.

Tillage GHG emissions

Key opportunities to reduce GHG emissions:

» *Reduce tillage*

Minimum tillage involves reducing the number of times a paddock is cultivated for crop production. Reducing tillage can result in reduced fuel use and losses of soil carbon. Barber [16] found that vegetable production using full cultivation consumed 300 l/ha of diesel per crop, while minimum tillage reduce fuel use by 40%, to 180 l/ha.

Not only does cultivation require a lot of energy, but it also increases loss of soil carbon because of increased soil aeration and exposure soil organic matter otherwise physically protected by soil structure. Numerous studies have demonstrated increased losses of carbon relating to tillage, however losses vary depending on soil type and type of tillage used. Luna *et al* [17] found that soil carbon losses increased by 500% (7.2 t/ha) 19 days after cultivation with a mouldboard plough.

The loss of soil carbon has follow-on implications for GHG emissions including increased soil strength, further increasing fuel use during cultivation; and reduced soil structural stability, reducing soil aeration and increasing nitrous oxide emissions.

R, D & E needs:

- Benchmark current best management practices for reduced tillage in vegetable production systems.
- Undertake research on new minimum tillage systems for the vegetable industry.
- Quantify carbon losses caused by different tillage practices on a range of soil types.
- Improved understanding of effects of occasional strategic tillage.

Pre-cooling of produce

Key opportunities to reduce GHG emissions:

» *Use the most efficient method of cooling*

» *Follow best practice procedures for cooler used*

» *Monitor cooling efficiency*

Energy use in cooling and storing produce was identified by a group of Mornington Peninsular farmers as being one of the major costs and uses of energy in their system [15].

Research from the USA has demonstrated that energy use efficiency of cooling systems varies with the type of cooler used [18]. Vacuum coolers are the most efficient, followed by hydro coolers, water spray vacuum coolers and forced-air coolers (Table 4). Part of the reason for the high efficiency of vacuum cooling is that it removes heat only from the product being cooled (low non-product heat input). The other types of coolers remove heat from fans, pumps, infiltration of outside air, heat conducted through exterior walls, lights, forklifts, and people working in the cooler. Variation in operational procedures is another major reason for the difference between cooler types. For example, most forced-air coolers are used for some short-term product storage, which contributes to their low energy efficiency.

There is also significant variation among coolers of the same type. An inefficient vacuum cooler can have lower energy efficiencies than an efficient hydro cooler. Variabi1ity among coo1ers of the same type can be caused by not using a cooler at maximum capacity; type of commodity cooled in a vacuum cooler, (cauliflower cools less efficiently than lettuce); and operational procedures (such as not turning off equipment between cooling cycles).

R, D & E needs:

- Produce information fact sheet for the industry on the GHG consequences of different cooling techniques.

Table 4. Typical energy efficiency ranges for initial cooling operations. Energy coefficient is the cooling work done divided by energy consumed. High coefficients represent efficient electricity use [19].

Type of cooler	Range of Energy Coefficients
Vacuum	2.5 – 1.5
Hydro	2.3 – 0.7
Forced air	1.5 – 1.4

Refrigerated storage

Key opportunities to reduce GHG emissions:

» *Pre-cool produce with efficient pre-cooler (eg. vacuum cooler)*

» *Take steps to minimise external heat entering the cooler*

» *Use efficient refrigeration equipment*

Energy use in a cold storage facility is affected by the amount of heat the refrigeration equipment must remove and the efficiency of the equipment.

The main sources of heat in a facility for long-term storage are transmission through walls, evaporator coil fans, lights, air leakage, and respiration of the stored commodity [19]. Methods of minimising heat required to be removed by the refrigerator include [19]:

- Increase insulation and paint cold storage facility exterior a light colour to minimise heat entering through walls.
- Shade cold storage facility from direct sunlight. Sun shining on walls and roof dramatically increase the effective outside temperature, increasing heat flow into a storage facility.
- Lights in the cold storage room should be turned off when not needed.
- Use plastic flap doors to reduce infiltration of warm outside air during loading and unloading.
- Seal around openings for pipes and electrical conduits.
- Heat produced by respiration of the stored commodity can be minimized by keeping the commodity minimum recommended storage temperatures.
- Pre-cool produce in an efficient pre-cooler

Refrigeration system design has a great effect on energy use. Options to improve refrigerator efficiency include:

- Maintaining the temperature of the refrigerant fluid as low as possible after it is cooled in the condenser. A facility maintaining 0°C and a condensing temperature of 52°C requires 50 percent more power than one that operates at a condensing temperature of 35°C.
- Use evaporative condensers rather that air cooled units in warm climates.
- Maintaining highest possible suction pressure reduces compressor energy use.
- Use large evaporator coils and a control system that increases suction pressure as demand on the refrigeration system is reduced.
- Use a compressor system that operates efficiently over the required range of refrigerant flows. Screw compressors operate efficiently only at flow rates near their maximum capacity. Use several in parallel, shutting down those that are not needed, or consider using reciprocating compressors for peak loads. They operate efficiently over a large range of refrigerant flows.

R, D & E needs:

- Produce information fact sheet for the industry on the GHG consequences of different refrigeration techniques.

Packaging

Key opportunities to reduce GHG emissions:

» *Use less packaging*

» *Use packaging made from recycled material*

» *Use packaging that is recyclable*

GHG emissions associated with packaging can be minimised by reducing the amount of packaging used in the industry. Where packaging is necessary, the use of packaging made from recycled materials can greatly reduces the embodied emissions of the packaging (see 'Manufacture of packaging' section above), although this does vary depending on material used (Table 1).

It should be noted that packaging has a number of benefits including prolonging shelf-life, and protecting produce from damage and contamination, all of which results in greater product utilisation efficiency and reduced waste. This means that energy and inputs that go into vegetable production is consumed more efficiently.

R, D & E needs:

- Produce information fact sheet for the industry on the GHG consequences of different packing materials and techniques.

Other direct GHG mitigation opportunities

Specialised production systems such as hydroponics, glasshouse systems and organic farming systems have not been covered in this paper. These systems are likely to have quite different carbon footprints to conventional vegetable production systems and potentially quite different options available to minimise greenhouse gas emissions. The overall effect of these systems on the carbon footprint of a unit of produce needs investigation.

Hydroponic and glasshouse systems are likely to result in more efficient use of input (high production per unit input), but are likely to use more energy in climate control (heating/cooling) and have greater embodied emissions in infrastructure.

The implication of organic farming also needs to be further investigated. Organic farming systems have a reduced reliance on synthetic fertilisers and agrochemicals, however there is an increased reliance on composts and animal manures which contribute their own GHG emissions. The application of composts and manures can result in high losses of nitrous oxide depending on climatic conditions after application, but also increase soil carbon levels. The net effect of these factors needs further investigation.

III. Post-farm (downstream) greenhouse gas mitigation options

Transport of produce to market

Key opportunities to reduce GHG emissions:

- » *Use energy efficient and low GHG emitting modes of transport*
- » *Use the most energy efficient low GHG emitting fuels in transport*
- » *Maximise volume of product transported per trip*
- » *Reduced distance produce needs to be transported*

The same principles applied to reducing GHG emissions associated with the transport of inputs to farm apply to reducing those associated with transporting produce to market (see ‘Transport of inputs to farm’ above).

An additional consideration with transportation of produce to market is the time it takes to reach the market and the effect this has on quality. For example, road transport may have a larger impact on carbon footprint, but gets produce to market more quickly than rail transport, thereby optimising product quality and reducing waste.

Reducing the distance to market can be achieved by selling more produce locally, or as part of an industry approach, ensuring vegetables are grown as close as possible to markets.

Refrigeration during transport and storage

Key opportunities to reduce GHG emissions:

- » *Pre-cool produce with efficient pre-cooler (eg. vacuum cooler)*
- » *Take steps minimise external heat entering the cooler*
- » *Use efficient refrigeration equipment*
- » *Minimise time spent in transport*

Other post-farm GHG mitigation opportunities

Additional processing such as drying, canning and freezing have not been considered in this report, however each of these processes are likely to present opportunities to reduce GHG emissions. It should be noted that each of these processes acts to extend shelf-life of products, resulting in greater product utilisation efficiency and reduced waste. This means that energy and inputs the go into vegetable production is consumed more efficiently.

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