Vegetable Industry Carbon Footprint Scoping Study

Discussion Paper 4

Preliminary estimation of the carbon footprint of the Australian vegetable industry

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DISCUSSION PAPER 4

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Preliminary Estimation of the Carbon Footprint of the Australian Vegetable Industry

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Purpose of the paper:

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.

Funded by Horticulture Australia Limited

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Preliminary Estimation of the Carbon Footprint of the Australian Vegetable Industry

Discussion paper 4.

Vegetable Industry Carbon Footprint Scoping Study – Discussion Papers & Workshop

HAL Project VGO8107

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Contents

Abbreviations

Energy & Power

J	joule	basic unit of energy
kJ	kilojoule	1,000 joules
MJ	megajoule	1,000,000 joules
GJ	gigajoule	1,000,000,000 joules
W	watt	basic unit of power = 1 joule per second
kW	kilowatt	1,000 watts
kWh	kilowatt-hour	3.6 MJ

Others

ha	hectare	10,000 square metres
g	gram	
kg	kilogram	1,000 grams
t	tonne	1,000 kilograms
ml	millilitre	
L	litre	1,000 millilitres
CO_2	carbon dioxide	
ai	active ingredient	
IPCC	International Panel on Climate Change	

Executive Summary

This report has undertaken a preliminary carbon footprint analysis for the Australian vegetable industry based on readily available data. It discusses the data needs for developing a carbon footprint analysis and discusses the current availability of suitable data. 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.

Accounting for greenhouse gas (GHG) emissions is fast becoming an imperative for the horticulture industry. The rise in Government interest in emissions mitigation, the potential for industry involvement in emissions trading schemes, and the community awareness of the impact of GHG emissions, all provide an opportunity for the Australian vegetable industry to be able to: account for the level of greenhouse gases they are responsible for; respond to community pressure to reduce these emissions; respond to market pressures to account for and measure the impact of production on the environment; and proactively promote a corporate social responsibility to addressing the impact of production on the environment.

The Australian vegetable industry is interested in identifying its carbon footprint in response to these external pressures. The aim of this discussion paper is to review the data requirements and quality of currently available data for such a study. Specifically the paper addresses:

(i) The availability and applicability of emissions factors for Australian vegetable industry.

(ii) Limitations on data availability.

(iii) The parts of the production system making greatest contributions to GHG emissions.

The work for this paper has illustrated that it in many cases data on GHG emissions factors suitable for the vegetable industry, or even data on industry practices, are not readily available. The consequence of this is that it has not been possible to even make a first approximation of the GHG emissions occurring from some components of the Australian vegetable industry's carbon footprint. In this paper we have focused on what are thought to be the largest industry related emissions including:

i) Upstream emissions from: fertiliser production, agrochemical production, electricity irrigation pumping, and embedded emissions for fuel.

ii) Direct emissions from: nitrous oxide due to fertiliser use and carbon dioxide (CO_2) emissions from tractor use.

Using the best readily available emissions data, and industry practice data based largely on information from NSW, a preliminary estimation of the total vegetable industry emissions form these sources is: 1,047,008 t CO_2-e yr^{-1},

This is approximately one-third the value of other estimates[1].

However, this value should be used with considerable caution and only after the assumptions underlying this figure are understood.

[1] see Discussion Paper 5 (Deuter 2008)

This report highlights the need for greater work to collect relevant carbon footprint data for the Australian vegetable industry, and horticulture industry in general, and to asses the confidence values around data estimates.

Introduction

To produce a reliable footprint, it is important to follow a structured process and to classify all the possible sources of emissions thoroughly. A common classification is to group and report on emissions by the level of control which an organisation has over them. On this basis, greenhouse gas emissions can be classified into two main types, direct emissions (on-site, internal) and indirect emissions (off-site, external, embodied, upstream, downstream).

The most important greenhouse gas arising from human activity is CO_2. Virtually all human activities cause CO_2 emissions, such as using electricity generated from fossil fuel power stations, burning gas for heating or driving a petrol or diesel car. Furthermore every product or service that humans consume indirectly creates CO_2 emissions by the energy required for their production, transport and disposal. As well as CO_2 five other greenhouse gases are regulated by the Kyoto Protocol, as they are emitted in significant quantities by human activities and contribute to climate change. These are Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6). Producing a carbon footprint is therefore a complex process that has to consider different gases produced and the consequences of direct and indirect emissions. One of the greatest confusions between different carbon footprint analyses is which indirect emissions have been included, and what level of embodied emissions have been included in the indirect emissions values (see Discussion Paper 1).

This report divides GHG emissions into three sections: i) Pre-farm (upstream-indirect), ii) On-farm (direct or Stage 1), and iii) Post-farm (downstream-indirect). The items included in the indirect emissions are subjective, however, an attempt has been made to include those that are thought to make a significant contribution to the total industry footprint.

Emission factors

Definition

Fundamental to the development of a carbon footprint is the concept of emissions factors. Emission factors provide a simple conversion from an identifiable and quantifiable activity into a quantity of GHG emissions. Activities are selected on their ease of being able to be monitored, and can consist of a range of complex sub-activities. Examples of activities can range from just living (such as a cow) to mining raw materials. An emission factor can be defined as the average emission rate of a given GHG relative to the intensity of a specific activity. Emission factors are usually expressed as the weight of GHG emitted divided by the unit weight, volume, distance, or duration of the activity causing the emission. Importantly, emission factors assume a linear relation between the intensity of the activity and the emission resulting from this activity [1]. In this way emission factors are used to derive estimates of GHG emissions based on, for example, the amount of fuel combusted, the number of animals kept, industrial production levels, distances travelled, or similar activity data.

Emissions of different GHGs are commonly converted into CO_2 equivalent (CO_2-e) based on their 100 year global warming potential. This allows a single figure for the total impact of all emissions sources to be produced in one standard unit. Conversion factors of different GHGs to CO_2-e are calculated by the International Panel on Climate Change (IPCC) and are referred to as the Global Warming Potential (GWP). This index is used to convert relevant non-carbon dioxide gases to a CO_2 equivalent (CO_2-e) by multiplying the quantity of the gas by its GWP (Appendix 1).

Uncertainty associated with emission factors

The level of uncertainty in estimating GHG emissions depends significantly on the source category. For example, CO_2 emissions from the combustion of fuel can be estimated with a high degree of certainty regardless of how the fuel is used. This is because carbon is almost completely oxidised during fuel combustion and all the carbon atoms in the fuel will be present in the exhaust gases as CO_2. The emissions therefore depend almost exclusively on the carbon content of the fuel, which is generally known with a high degree of precision. In contrast, nitrous oxide (N_2O) emissions from agricultural soils are highly uncertain because they depend very much on both the exact conditions of the soil, the application of fertilisers and meteorological conditions. The emission factors therefore vary considerably with the type of activities, and local validation is required.

Methods for estimating emission factors

Direct measurement

For direct measurement data to be adequate it needs to be collected over a period of time, and to be representative of operations for the whole year. A continuous emission monitoring system provides a continuous record of emissions over time, usually by reporting GHG concentration. Once the concentration is known, emission rates are obtained by multiplying the GHG concentration by the volumetric gas or liquid flow rate.

Mass balance

The mass balance technique involves identification of the quantity of substance going in and out of an entire facility, process, or piece of equipment. Emissions can be calculated as the difference between input and output of each listed substance. Accumulation or depletion of the substance within the equipment should be accounted for in calculation.

Engineering calculation

An engineering calculation is an estimation method based on physical/chemical properties (eg. vapour pressure) of the substance and mathematical relationships (eg. ideal gas law). Fuel analysis is an example of an engineering calculation based on the application of conservation laws, if fuel rate is measured.

I. Pre-farm (upstream) greenhouse gas emissions

Pre-farm green house gas (GHG) emissions are those produced through the production of materials or inputs that go towards on-farm production. These are also referred to as 'upstream', 'embodied' or 'indirect' GHG emission.

'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 product. Embodied energy usually makes up the majority of the 'embodied emissions'. These 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 industry's carbon footprint. The upstream greenhouse gas emissions can be classified into three major components, Figure 1 [3]:

- Direct – the energy supplied directly in the form of fuels and electricity.
- Indirect – the energy used on fertilisers, agrichemicals, seeds, and animal feed supplements.
- Capital – energy used to manufacture items of capital equipment such as farm vehicles, machinery, buildings, fences and methods of irrigation.

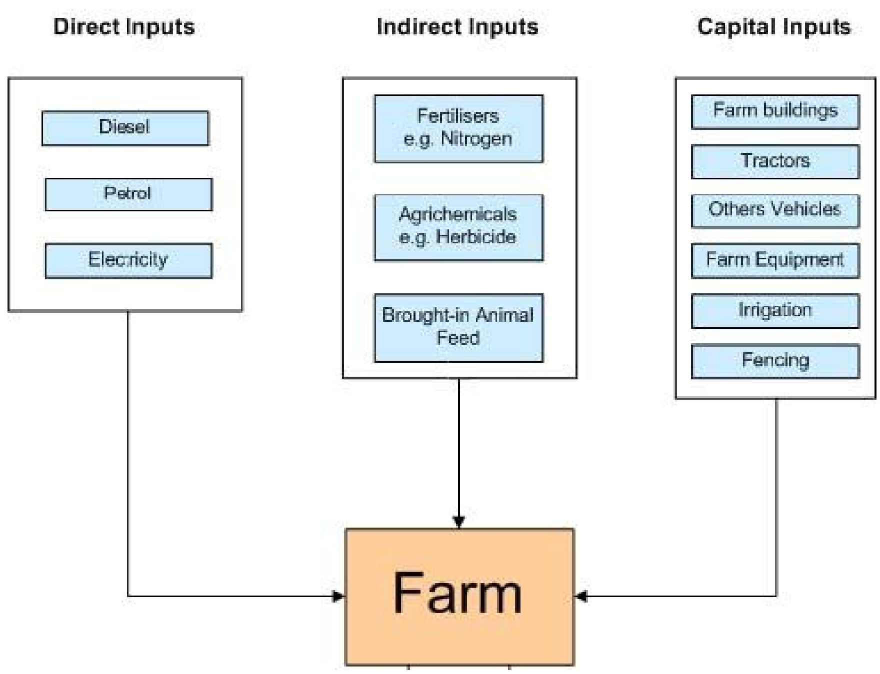


Figure 1 Farm inputs (Saunders et al. 2006)

Fertiliser production

Fertilisers are an important input into the production of vegetables crops. Upstream GHG emissions from fertilisers occur mainly due to energy requirement for their production. The quantity of upstream GHG emitted varies dramatically depending on the form of active ingredient and the process of manufacture. This is illustrated in Figure 1 of Discussion Paper 6, which shows the average GHG emissions (tCO_2–e/ t product) produced from fertiliser production in Europe for various formulations.

The emission factor (EF) values for each fertiliser component are likely to be different with each production methods used. There is no data available on energy use or EF values for the Australian fertiliser industry. Wells (2001) [3, 4] presented data on EF values for different fertiliser components (Table 1). These data were used by Saunders *et al*. 2006 to estimate pre-farm GHG emissions from vegetable crops grown in NZ and UK. As an interim, in absence of any Australian data, these can be assumed as the best values for the Australian vegetable industry.

Table 1. Energy requirement to manufacture fertiliser components and associated CO_2 emissions (EF) (Wells 2001; cited by Saunders *et al.* 2006).

Component	**Energy use (MJ/kg)**	**EF (CO_2-e/MJ)**
N	65	0.05
P	15	0.06
K	10	0.06
S	5	0.06
Lime	0.6	0.72
Gypsum		0.45[a]

[a] t CO_2-e per tonne of amount used

The GHG emission for each fertiliser type can be calculated using:

$$F_{GHG} = A \times E \times EF / 1000$$

Where: F_{GHG} is the amount of green house gas emission (t CO_2-e); A is the total amount of each fertiliser used (kg); E is the energy required to manufacture each fertiliser component (MJ/kg); EF is the emission rate for each component of fertiliser (kg CO_2-e /MJ) (Table 1); 1000 converts kg CO_2-e to tonnes.

If the exact amount of fertiliser used is not known, then the pre-farm GHG for each component can be estimated using:

$$F_{GHG} = R \times L \times E \times EF / 1000$$

Where: R is the rate of use for each fertiliser component (kg/ha); L is the cropped area (ha); other terms as defined above.

Total amount of GHS emissions due to fertiliser use will be:

$$T_{GHG} = \sum F_{GHG}$$

Where: T_{GHG} is the total amount GHG emissions; F_{GHG} is the amount of GHG emissions for each component of fertiliser.

The total amount of GHG emissions for the entire vegetable industry, $\mathbf{V_{GHG}}$, can be estimated by summing the values of T_{GHG}.

If the values of A or R are not available then the GHG emissions for the entire vegetable industry can be estimated using:

$$\mathbf{V_{GHG} = T \times FN \times E \times EF / 1000}$$

Where: T is the total amount of agricultural fertilisers used (kg); FN is the fraction of fertiliser used in vegetable industry (the only data found for this fraction is for horticulture/vegetable crops by State, Table 2); other terms were defined earlier.

Table 2. Fraction of each state's total nitrogen fertiliser use that goes for horticulture/vegetable production in Australia (NGAF 2008).

	Fraction (average) of total fertilisers used by various states						
	NSW	NT	QLD	SA	TAS	VIC	WA
Fraction	0.03685	0.91818	0.07663	0.09306	0.22901	0.11449	0.01621

Australian Vegetable Industry Estimate

National information on Australian vegetable production fertiliser use was not readily available. However, fertiliser rates for most vegetable crops are available in a Department of Agriculture study on farm gross margins in the NSW vegetable industry (Table 3). To make a preliminary estimate of the pre-farm fertiliser GHG emissions for the national Australian vegetable industry these fertiliser rates have been assumed for the whole country. The total fertiliser use was obtained by multiplying these rates by the national production area (Table 3). Each fertiliser's ingredients were calculated and using the appropriate conversion (Table 4). The emissions factors were used to calculate the embedded energy and GHG emissions (Table 5).

Table 3. Land area, yield and rate of fertiliser used for each crop

Crop type	Crop statistics [A]			Fertiliser rate[B]			
	Production (t)	Area (ha)	Yield (t/ha)	DAP (kg/ha)	Single super (kg/ha)	Ammonium nitrate (kg/ha)	Urea (kg/ha)
Asparagus	5,609	1,302	4	150		150	
Beans, french and runner[C]	28,844	4,978	6	300			
Beetroot	40,765	1,279	32	300			
Broccoli	46,031	7,135	6	500			400
Cabbages	81,563	2,020	40	250	200	350	
Capsicums (excluding chillies)	56,313	2,156	26	500			500
Carrots – fresh	271,464	5,715	48		500	400	
Cauliflowers	69,793	3,580	20	500			125
Celery[C]	48,542	991	49	200			
Chillies (excluding capsicums) [C]	1,957	163	12	200			
Cucumbers[C]	41,931	577	73	200			
Green peas- Fresh market (pod weight) [C]	533	277	2	200			
Green peas-processing (shelled weight)	15,232	3,354	5	500			400
Lettuces	271,251	10,011	27	250	200	350	
Melon - Rock and cantaloupe	68,105	2,628	26	300	200		
Melon – water	136,861	4,421	31	200	200		200
Mushrooms	42,739	181	236	50			
Onions	246,496	5,413	46	400		300	
Potatoes	1,211,988	34,096	36	500			250
Pumpkins	102,505	5,968	17	200	200		200
Sweet corn	62,575	5,942	11	500			500
Tomatoes	296,035	7,293	41	46	24		
Zucchini and button squash	23,704	2,438	10	200	200		200

[A] data source ABS
[B] data source NSW Department of agriculture
[C] Average rate used

Table 4. N, P, K and S content in each fertiliser type

	Type of fertilisers			
	DAP	Single super	Ammonium nitrate	Urea
N (per cent)	18	0	35	46
P (per cent)	46	21	0	0
K (per cent)	0	0	0	0

S (per cent)	0	25	0	0

Table 5. Various components of fertiliser use and associated energy required for growing various vegetable crops.

Crop Type	Total N, P & S (K=0 in each fertiliser)			Energy Use			
	N (kg)	P (kg)	S (kg)	N (MJ)	P (MJ)	S (MJ)	Total energy use (PJ)
Asparagus	103,509	89,838	0	6,728,085	1,347,570	0	0.008
Beans, french and runner	268,812	686,964	0	17,472,780	10,304,460	0	0.028
Beetroot	69,066	176,502	0	4,489,290	2,647,530	0	0.007
Broccoli	1,954,990	1,641,050	0	127,074,350	24,615,750	0	0.152
Cabbages	338,350	317,140	101,000	21,992,750	4,757,100	505,000	0.027
Capsicums (excluding chillies)	689,920	495,880	0	44,844,800	7,438,200	0	0.052
Carrots-fresh	800,100	600,075	714,375	52,006,500	9,001,125	3,571,875	0.065
Cauliflowers	528,050	823,400	0	34,323,250	12,351,000	0	0.047
Celery	35,676	91,172	0	2,318,940	1,367,580	0	0.004
Chillies (excluding capsicums)	5,868	14,996	0	381,420	224,940	0	0.001
Cucumbers	20,772	53,084	0	1,350,180	796,260	0	0.002
Green peas-Fresh market (pod weight)	9,972	25,484	0	648,180	382,260	0	0.001
Green peas-Processing (shelled weight)	918,996	771,420	0	59,734,740	11,571,300	0	0.071
Lettuces	1,676,843	1,571,727	500,550	108,994,763	23,575,905	2,502,750	0.135
Melon - Rock and cantaloupe	141,912	473,040	131,400	9,224,280	7,095,600	657,000	0.017
Melon - water	565,888	592,414	221,050	36,782,720	8,886,210	1,105,250	0.047
Mushrooms	1,629	4,163	0	105,885	62,445	0	0.000
Onions	958,101	995,992	0	62,276,565	14,939,880	0	0.077
Potatoes	6,989,680	7,842,080	0	454,329,200	117,631,200	0	0.572
Pumpkins	763,904	799,712	298,400	49,653,760	11,995,680	1,492,000	0.063
Sweet corn	1,901,440	1,366,660	0	123,593,600	20,499,900	0	0.144
Tomatoes	60,386	191,077	43,758	3,925,093	2,866,149	218,790	0.007
Zucchini and button squash	312,064	326,692	121,900	20,284,160	4,900,380	609,500	0.026

Table 6. Pre-farm energy use and CO2 emissions associated with synthetic fertiliser use.

Crop	Area (ha)	Energy use (PJ)	t CO_2-e/ha	t CO_2-e/kg	Total emissions (t CO_2-e/yr)
Asparagus	1,302	0.008	0.32	0.07	417
Beans, french and runner	4,978	0.028	0.30	0.05	1,492
Beetroot	1,279	0.007	0.30	0.01	383
Broccoli	7,135	0.152	1.10	0.17	7,831
Cabbages	2,020	0.028	0.72	0.02	1,446
Capsicums (excluding chillies)	2,156	0.052	1.25	0.05	2,689
Carrots - fresh	5,715	0.068	0.62	0.01	3,569
Cauliflowers	3,580	0.047	0.69	0.04	2,457
Celery	991	0.004	0.20	0.00	198
Chillies (excluding capsicums)	163	0.001	0.20	0.02	33
Cucumbers	577	0.002	0.20	0.00	115
Green peas- Fresh market (pod weight)	277	0.001	0.20	0.10	55
Green peas- Processing (shelled weight)	3,354	0.071	1.10	0.24	3,681
Lettuces	10,011	0.138	0.72	0.03	7,165
Melon - Rock and cantaloupe	2,628	0.018	0.37	0.01	966
Melon - water	4,421	0.048	0.57	0.02	2,505
Mushrooms	181	0.000	0.05	0.00	9
Onions	5,413	0.077	0.74	0.02	4,010
Potatoes	34,096	0.572	0.87	0.02	29,774
Pumpkins	5,968	0.065	0.57	0.03	3,381
Sweet corn	5,942	0.144	1.25	0.12	7,410
Tomatoes	7,293	0.007	0.05	0.00	394
Zucchini and button squash	2,438	0.026	0.57	0.06	1,381
National Total					**81,362**

Agrochemical production

The vegetable industry uses a wide range of agrochemicals for a variety of purposes. Similar to fertilisers the energy component in chemicals is mainly from their production and transport. There is no information available for energy content of agrochemicals produced in Australia. However, information is available in the international literature on the energy content of various agrochemicals (Table 7) [4,5]. It is assumed that these would be similar for Australian vegetable industry.

Table 7. Energy used to manufacture agrochemicals and associated CO_2 emissions [4,5].

Agrochemicals	Production of active ingredient (ai)	Formulation, packaging and transport	Total energy (E) (MJ/kg of ai)	Emission factor (EF) (kg CO_2/MJ)
Herbicide (Paraquat, Diquat and Glyphosphate)	440	110	550	0.06
Herbicide (General)	200	110	310	0.06
Insecticide	185	130	315	0.06
Fungicide	100	110	210	0.06
Plant growth regulator	65	110	175	0.06

The GHG for each agrichemical can be calculated using:

$$\mathbf{C_{GHG} = A \times E \times EF / 1000}$$

Where: C_{GHG} is the amount of green house gas emission (t CO_2-e); A is the total amount of each agrochemical used (kg); E is the energy required to manufacture each agrichemical type (MJ/kg of active ingredient); EF is the emission rate for each agrochemical (kg CO_2-e /MJ).

Total amount of GHS emissions due to agrochemical use can be calculated by:

$$TC_{GHG} = \sum C_{GHG}$$

Where: TC_{GHG} is the total amount GHG emissions; C_{GHG} is the amount of GHG emissions for each type of agrochemical use.

Australian Vegetable Industry Estimate

National information on Australian vegetable production agrochemical use was not readily available. However, agrochemical use for most NSW vegetable crops is available in a NSW Department of Agriculture study on farm gross margins (Data not shown). To make a preliminary estimate of the pre-farm agrochemical GHG emissions for the national vegetable industry these rates have been assumed applicable for the whole country. The total agrochemical use was obtained by multiplying these rates by the national production area. Each agrochemical has been multiplied by a conversion factor to obtain approximate active ingredients (0.5 for herbicides and 0.25 for insecticides and fungicides). The emissions factors (Table 7) were used to calculate the embedded energy due to the manufacturing of agrochemicals for each vegetable crop (Table 8) and to convert this into equivalent pre-farm GHG emissions (Table 9).

Table 8 Agrochemical and associated energy use

Crop type	Agrichemicals use (L)				Energy use (GJ)				Total energy use (GJ)
	Insecticide	Herbicide	Herbicide (general)	Fungicide	Insecticide	Herbicide	Herbicide (general)	Fungicide	
Asparagus	2,083	5,208	3,255	0	164	1432	505	0	2,101
Beans, french and runner	0	0	0	0	0	0	0	0	-
Beetroot	0	0	0	0	0	0	0	0	-
Broccoli	53,513	21,405	4	93,112	4214	5886	1	4888	14,990
Cabbages	15,150	6,060	0	0	1193	1667	0	0	2,860
Capsicums (excluding chillies)	19,404	9,702	0	41,395	1528	2668	0	2173	6,369
Carrots – fresh	9,144	0	0	50,292	720	0	0	2640	3,360
Cauliflowers	5,728	0	0	41,170	451	0	0	2161	2,613
Celery	1,586	0	0	11,397	125	0	0	598	723
Chillies (excluding capsicums)	261	0	0	1,875	21	0	0	98	119
Cucumbers	923	0	0	6,636	73	0	0	348	421
Green peas- Fresh market (pod weight)	443	0	0	3,186	35	0	0	167	202
Green peas- Processing (shelled weight)	5,366	0	0	0	423	0	0	0	423
Lettuces	50,055	0	0	125,138	3942	0	0	6570	10,512
Melon - Rock and cantaloupe	27,594	0	0	45,990	2173	0	0	2414	4,588
Melon – water	46,421	0	0	22,105	3656	0	0	1161	4,816
Mushrooms	0	0	0	2,263	0	0	0	119	119
Onions	9,743	0	0	0	767	0	0	0	767
Potatoes	34,096	0	0	136,384	2685	0	0	7160	9,845
Pumpkins	41,776	0	0	44,760	3290	0	0	2350	5,640
Sweet corn	106,956	35,652	3	0	8423	9804	0	0	18,228
Tomatoes	51,051	0	0	218,790	4020	0	0	11486	15,507
Zucchini and button squash	9,752	0	0	24,380	768	0	0	1280	2,048
Total									106,249

Table 9 Energy use and green house gas emissions due to agrochemical use

Crop	Energy use (GJ)	t CO_2-e/ha	t CO_2-e/kg	Emissions (t CO_2-e/yr)
Asparagus	2,101	0.10	0.02	126
Beans, french and runner	0	0.00	0.00	0
Beetroot	0	0.00	0.00	0
Broccoli	14,990	0.13	0.02	899
Cabbages	2,860	0.08	0.00	172
Capsicums (excluding chillies)	6,369	0.18	0.01	382
Carrots - fresh	3,360	0.04	0.00	202
Cauliflowers	2,613	0.04	0.00	157
Celery	723	0.04	0.00	43
Chillies (excluding capsicums)	119	0.04	0.00	7
Cucumbers	421	0.04	0.00	25
Green peas- Fresh market (pod weight)	202	0.04	0.02	12
Green peas- Processing (shelled weight)	423	0.01	0.00	25
Lettuces	10,512	0.06	0.00	631
Melon - Rock and cantaloupe	4,588	0.10	0.00	275
Melon - water	4,816	0.07	0.00	289
Mushrooms	119	0.04	0.00	7
Onions	767	0.01	0.00	46
Potatoes	9,845	0.02	0.00	591
Pumpkins	5,640	0.06	0.00	338
Sweet corn	18,228	0.18	0.02	1,094
Tomatoes	15,507	0.13	0.00	930
Zucchini and button squash	2,048	0.05	0.01	123
National Total				**6,375**

Electricity generation

Electricity is produced using a range of different technologies each of which have different GHG 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.

The emissions factors for the consumption of purchased electricity are provided in Table 10. State emissions factors are reported because electricity flows between states are constrained by the capacity of the inter-state interconnections and in some cases there are no interconnections (National Greenhouse Accounts Factors, 2008). The factors estimate emissions of CO_2, CH4 and N_2O expressed together as CO_2 equivalent (CO_2-e).

Table 10. Energy content (E) and emission factors (EF 1, EF2) for consumption of purchased electricity from the grid—for end users (not distributors)[A]

Sate	E [B]	EF1	EF2
	MJ/kW	kg CO_2-e/kWh	kg CO_2-e/GJ
NSW and ACT	3.6	0.89	249
VIC	3.6	1.22	340
QLD	3.6	0.91	252
SA	3.6	0.84	233
WA	3.6	0.87	242
TAS	3.6	0.12	35
NT	3.6	0.69	190

[A] Source: Department of Climate Change 2007.

[B] [4]

The greenhouse gas emissions in tonnes of CO_2-e attributable to the quantity of electricity used may be calculated with the following equation.

$$E_{GHG} = Q \times EF1 / 1000$$

Where: Q is the electricity consumed by the vegetable industry expressed in kWh; and EF is the emission factor expressed in kg CO_2-e/kWh; 1000 converts kg CO_2-e to tonnes.

Or this may be expressed as:

$$E_{GHG} = Q \times E \times EF2 / 1000$$

Where: Q is the electricity consumed expressed in GJ, E is the energy content (MJ/kWh).

The main on-farm uses for electricity are for pumping water and cooling or storing produce. The information on these activities relevant for the vegetable industry is described in the sections below.

Australian Vegetable Industry Estimate from Irrigation

National information on Australian vegetable production water use was not readily available. However, water use for most NSW vegetable crops is available in a NSW Department of Agriculture study on farm gross margins (data not shown). To make a preliminary estimate of the pre-farm GHG emissions associated with the electric pumping of irrigation water for the national vegetable industry, these rates have been assumed applicable for the whole country. The total water use was obtained by multiplying these rates by the national production area. An energy factor for pumping water of 4 GJ ML^{-1} has been assumed, although this is likely to be variable in different farming systems. An average emissions factor for all states was used to calculate the pre-farm GHG emissions.

Table 11. Energy use and CO_2 emissions associated with irrigation water

Crop	Water (ML)	Total energy use (GJ)	CO_2 (t/ha)	CO_2 (t/kg)	Total CO_2 (t/yr)
Asparagus	10,416	41,664	7.04	1.63	9,166
Beans, French and runner	29,868	119,472	5.28	0.91	26,284
Beetroot	7,035	28,138	4.84	0.15	6,190
Broccoli	42,810	171,240	5.28	0.82	37,673
Cabbages	8,080	32,320	3.52	0.09	7,110
Capsicums (excl. chillies)	17,248	68,992	7.04	0.27	15,178
Carrots	31,433	125,730	4.84	0.10	27,661
Cauliflowers	14,320	57,280	3.52	0.18	12,602
Celery	5,946	23,784	5.28	0.11	5,232
Chillies (excl. capsicums)	978	3,912	5.28	0.44	861
Cucumbers	3,462	13,848	5.28	0.07	3,047
Green peas (processing shwf wt)	20,124	80,496	5.28	33.23	17,709
Green peas (Fresh market, pod weight)	1,662	6,648	5.28	0.10	1,463
Lettuces	40,044	160,176	3.52	0.13	35,239
Melon -Rock and cantaloupe	10,512	42,048	3.52	0.14	9,251
Melon –Water	35,368	141,472	7.04	0.23	31,124
Mushrooms	1,086	4,344	5.28	0.02	956
Onions	32,478	129,912	5.28	0.12	28,581
Potatoes	136,384	545,536	3.52	0.10	120,018

Pumpkins	47,744	190,976	7.04	0.41	42,015
Sweet corn	47,536	190,144	7.04	0.67	41,832
Tomatoes	43,758	175,032	5.28	0.13	38,507
Zucchini and button squash	19,504	78,016	7.04	0.72	17,164
National Total					**534,860**

Australian Vegetable Industry Estimate from Post-harvest

Postharvest electricity use is assumed in this paper to include electricity associated with all on-farm cooling and refrigeration, cleaning and packaging. We could not find any data that separated out these electricity use components.

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 [6]. The energy use efficiency of cooling systems varies with the type of cooler used [7]. Vacuum coolers are the most efficient, followed by hydro coolers, water spray vacuum coolers and forced-air coolers (see Table 1 in Discussion Paper 6). There is also significant variation among coolers of the same type. Energy use in cooling and refrigeration also varies depending on the type of product being cooled.

The most relevant data available on postharvest electricity use is for onion and vegetable production in New Zealand [5]. In that study, postharvest energy use for onions and potatoes was 1.9 GJ/ha and 10.7 GJ/ha respectively. Assuming, on average all Australian vegetable crops require the average of these two crops (6.3 GJ/ha) the Australian vegetable industry would require 705,083 GJ of energy for postharvest activities (assuming Australian vegetable industry covers 112,000 ha). The amount of GHG emitted in the production of this electricity would vary depending on source of electricity, which differs between states (Table 10). Using the average of all states (220 kg CO_2-e/GJ) the Australian vegetable industry would emit very approximately 155,000 t CO_2-e per year from postharvest electricity use.

Fuel production

Different fuel types cause different quantities of GHG emission during production. This is shown for a range of fuel types in Figure 3 of Discussion Paper 6. Fuels such as biodiesel have large upstream emissions relative to other fuels, but incur almost no direct emissions.

Australian Vegetable Industry Estimate

National information on Australian vegetable production fuel use was not readily available. However, fuel use required for most vegetable crops grown in NSW is available in a NSW Department of Agriculture study on farm gross margins (Data not shown). To make a preliminary estimate of the pre-farm GHG emissions associated with fuel use for the national vegetable industry, these usage rates have been assumed applicable for the whole country. The total fuel use was obtained by multiplying these rates by the national production area. An energy factor for diesel of 38.6 MJ L^{-1} has been assumed and an emissions factor of 12 g CO_2-e MJ^{-1} [8] was used to calculate the pre-farm GHG emissions.

Table 12. Fuel production and CO_2 emissions

Crop	Area (ha)	Producrion (t)	Annual diesel use (kL)	Total CO2 (tones/ha)	Total CO2 (tonnes/kg)	Total CO2 (tonnes)
Asparagus	1,302	5,609	548	0.20	0.05	254
Beans, french and runner	4,978	28,844	1,206	0.11	0.02	559
Beetroot	1,279	40,765	108	0.04	0.00	50
Broccoli	7,135	46,031	1,387	0.09	0.01	643
Cabbages	2,020	81,563	818	0.19	0.00	379
Capsicums (excluding chillies)	2,156	56,313	943	0.20	0.01	437
Carrots	5,715	271,464	769	0.06	0.00	356
Cauliflowers	3,580	69,793	354	0.05	0.00	164
Celery	991	48,542	240	0.11	0.00	111
Chillies (excluding capsicums)	163	1,957	39	0.11	0.01	18
Cucumbers	577	41,931	140	0.11	0.00	65
Green peas (processing shwf wt)	3,354	533	812	0.11	0.71	376
Green peas (Fresh market, pod weight)	277	15,232	67	0.11	0.00	31
Lettuces	10,011	271,251	3,487	0.16	0.01	1,615
Melon -Rock and cantaloupe	2,628	68,105	362	0.06	0.00	168
Melon -Water	4,421	136,861	1,074	0.11	0.00	498
Mushrooms	181	42,739	44	0.11	0.00	20
Onions	5,413	246,496	798	0.07	0.00	370
Potatoes	34,096	1,211,988	4,033	0.05	0.00	1,868
Pumpkins	5,968	102,505	406	0.03	0.00	188
Sweet corn	5,942	62,575	2,070	0.16	0.02	959
Tomatoes	7,293	296,035	3,013	0.19	0.00	1,396
Zucchini and button squash	2,438	23,704	672	0.13	0.01	311
National Total						**10,834**

Manufacture of packaging

Energy is used in the production of raw material (eg aluminium, plastic, glass etc), as well as in the manufacturing of that raw material into a useful products (eg plastic packaging). The embodied energy and emissions varies for different raw materials and is shown in Table 1 of discussion paper six.

Manufacture of packaging is likely to contribute to GHG emissions of the Australian vegetable industry, however we were unable to find any estimates of the quantity of packaging used, nor the type of materials packaging is made of.

This report does not include an estimate for the national contribution of GHGs in the vegetable industry for packaging.

Construction of buildings and building materials

As with packaging, all building materials have embodied energy and GHG emissions associated with their manufacture, however the quantity varies greatly for different materials. The embodied energy of various building materials is shown in Figure 4 of discussion paper six.

We could find information on the embodied energy of various building materials (see Figure 4, discussion paper six), but it seems unlikely that it will be possible to find any information on the proportion of different materials used in agricultural buildings in Australia, nor the area or number of buildings used in the vegetable industry. Wells (2001) has estimated emissions factors for general agricultural buildings (Table 13).

This report does not include an estimate for the national contribution of GHGs in the vegetable industry for buildings.

Table 13. Energy and CO_2 emission coefficients of buildings [3]

Item	Energy Use	Emission Rate (kg CO_2/MJ)	Working Life (years)
Dairy Shed	GJ = 24.2*sets of cups + 293	0.1	20
Other buildings	590 MJ/m^2	0.1	20

Manufacture of machinery

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].

Some energy coefficients, CO_2 emission factors and assumed working life of motor vehicles and farm implements are shown in Table 2 of Discussion Paper 6. Emissions factors include the embodied energy of the raw materials, the fabrication energy, an allowance for repairs and maintenance, and international freight.

We could find information on GHG emissions per unit weight of agricultural machinery (Table 2 of Discussion Paper 6), but could not find any information on the number of tractors and other implement used in the Australian vegetable industry, nor the average size of these machines.

This report does not include an estimate for the national contribution of GHGs in the vegetable industry for the manufacture of machinery.

Transport of inputs to farm

The major GHG emissions due to the transport of inputs, including fertilisers and seed stocks, occur from the consumption of fuel. The energy content of diesel, petrol and lubricants is readily available from a number of sources and its value is relatively uncontroversial [4]. The energy content and emission factors for various types of fuels are presented by the Department of Climate Change (NGAF, 2008) which can be used for estimation GHG emissions for Australian vegetable industry (Table 14).

Table 14. Fuel combustion emission factors various fuel types (NGAF 2008)

Description	E (GJ/kL)	EF (kg CO_2 e/GJ)
Petroleum and natural gas		
Motor gasoline (petrol)	34.2	67.0
Diesel(Automotive Diesel Oil)	38.6	69.8
Fuel oil	39.7	73.5
Liquefied petroleum gas	26.2	60.2
Natural gas		51.3
Biofuels		
Ethanol (molasses)	23.4	0.4
Ethanol (wheat starch waste)	23.4	0.4
Biodiesel (Canola)	23.4	0.4
Biodiesel (tallow)	23.4	0.4

Estimates of emissions from the consumption of transport fuels may be estimated with the following formula:

$$\mathbf{T_{GHG} = Q \times E \times EF/1000}$$

where Q is the quantity of fuel (kL); E is the energy content of fuel (GJ/kL); and EF is the relevant emission factor. Division by 1000 converts kilogram to tonnes.

Some example figures of the GHG emissions for different transport systems over different distances are show in Table 3 of Discussion Paper 6.

However because there is no readily available information on the distance travelled by inputs for the Australian vegetable industry, this report does not include an estimate for the national contribution of GHGs due to the transport of inputs.

R, D & E needs for pre-farm emissions:

- 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.
- Benchmarking of current electricity use for postharvest processing, cooling and refrigeration

II. On-farm (direct) greenhouse gas emissions

On-farm, or Stage 1 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. Direct emissions do not include electricity, which is a Stage 2 emission, or embedded contributions from other inputs, which are Stage 3 emissions.

The on-farm CO_2 emissions can be broadly classified into two categories: (i) nitrous oxide emissions from soil and (ii) CO_2 emissions due to energy use by various activities. The on-farm activities which are associated with energy use can be further categorised into: (a) tillage and other machinery use, (b) irrigation, (c) transport of crops from farm to shed, (d) packaging and storage, and (e) use of farm buildings.

Irrigation

Pumping of irrigation water is the second largest user of on-farm energy in the New Zealand vegetable industry [9], constituting 37 per cent of on-farm energy use. However, it is assumed that all pumping in the Australian vegetable industry uses electric pumps and therefore irrigation is covered in Section I.

Refrigeration and Cooling

It is assumed that all refrigeration and cooling in the Australian vegetable industry uses electrical power and is therefore covered in Section I.

Refrigeration also contributes to GHG emissions through the leakage of gases from air-conditioners and refrigerators, although this is probably small for the vegetable industry. This can be calculated using:

GHG emissions (t CO_2-e) = LR x CG x GWP

Where: LR is the annual loss rate; CG is charge of gases; and GWP is global warming potential.

For this report no estimate of these emissions for the Australian vegetable industry has been made.

Table 15. Industrial Processes emission factors and activity data for synthetic gases

Equipment type	Default annual loss rates	
	HFCs	SF6
Commercial air conditioning—chillers	0.09	

Commercial refrigeration - supermarket systems	0.23	
Industrial refrigeration including food processing and cold storage	0.16	
Gas insulated switchgear and circuit breaker applications		0.005 a

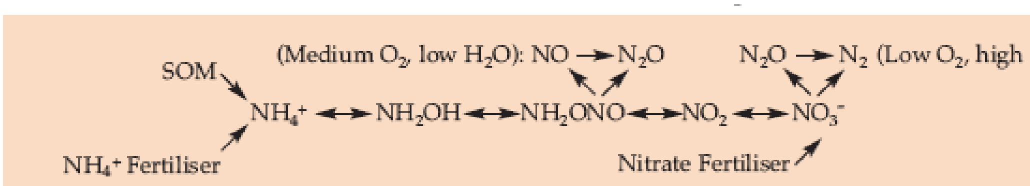
Source: IPCC 2006. Department of Climate Change 2007.

Nitrogen fertiliser use - Nitrous oxide emissions from soil

Nitrous oxide constitutes approximately 6 per cent of total CO_2-e emissions from Australia [10]. Of the total national nitrous oxide emission, 18 per cent result from the application of nitrogen fertilisers to agricultural soils and 22 per cent result from soil disturbance in agriculture, constituting 1.1 per cent and 1.3 per cent 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 per cent, horticulture = 0.13 per cent [11]), horticulture accounts for approximately 12 per cent of nitrogen fertiliser use in Australian agriculture [10], exemplifying the high rates of nitrogen fertiliser used in the horticultural industry. High nitrogen fertiliser application rates result in higher nitrous oxide emissions [10], 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.

Nitrous oxide is produced in soil by at least by three microbial-mediated mechanisms: (i) during ammonium oxidation to nitrite (nitrification) (ii) dissimilatory nitrate reduction (denitrification) and (iii) assimilatory nitrate reduction. Microbial assimilatory nitrate reduction is of minor importance in soils (less than 6 per cent of total nitrate reduction) because it is inhibited by very low concentrations of ammonium or soluble organic nitrogen present in soil. Dissimilatory nitrate reduction (denitrification) is probably the main source of N_2O in soil [12], although N_2O production by nitrification may sometimes be equally important. The generalised diagram below shows the first two mechanisms of nitrous oxide production from soil organic matter (SOM) and fertiliser in soil [12].



(1)

Recent experimental work on the application of fertilisers to different crop types in Australia and internationally has shown large variations from the IPCC default emission factor of 1.25 per cent across different classes of crop and pasture systems.

Variation in emission factor with region and cropping system is to be expected. A recent series of coordinated studies undertaken by the Cooperative Research Centre for Greenhouse Accounting has specifically addressed these issues and has established a set of emission factors suitable for Australian agricultural systems. However, this study does not include data for vegetable industry. As an interim approach, an average value of 0.021 is proposed for the vegetable industry (Table 16). The Australian vegetable industry also tends to use a lot of non-synthetic fertilisers for a range of reasons. Approximate emissions factors for these are listed in Table 17.

Table 16 Nitrous oxide emissions factors for synthetic fertiliser (DCC 2005).

Production system	Emission factor (Gg N_2O- N/Gg-N)
Irrigated pasture	0.004
Irrigated crop	0.021
Non-irrigated pasture	0.004
Non-irrigated crop	0.003
Sugar cane	0.0125
Cotton	0.005
Horticulture/vegetables	0.021

Table 17 N_2O emissions factors (per cent applied N) for manure applied to crops and pastures.

Fertilier type	Mean	Range
Organic	1.56	0.21 - 3.31
Sewage sludge	0.90	0.80 - 1.00
AWMS effluent	0.40	
Cattle slurry	0.25	0.04 - 0.57
Pig slurry	0.45	0.17 - 0.95
Poultry litter	0.50	0.50 - 0.50
Cattle faeces	0.5	
Dung	0.3	
Animal faeces	0.7	

Annual CO_2-e GHG emissions due to N_2O can be calculated using:

$$\mathbf{SL_{GHG} = E \times 310}$$

Where: SL_{GHG} is the amount of green house gas emission (t CO_2-e); E is the annual nitros oxide emissions from fertiliser (Gg N_2O); and 310 is the value (Appendix 1) used for converting Gg N_2O to t CO_2-e. The value of E can be calculated using:

$$\mathbf{E = M \times EF \times C_g}$$

Where: E is the annual emissions from fertiliser (Gg N_2O); M is the mass of fertiliser in production system applied averaged over three years (Gg N); EF is the emission factor (Gg N_2O-N/Gg N applied); and C_g is the 44/28 factor to convert elemental mass of N_2O to molecular mass.

Alternatively the mass of fertiliser applied to soil in the vegetable industry can be estimated using:

$$\mathbf{M = T \times FN}$$

Where: M is the mass of fertiliser applied (Gg N); T is the total mass of fertiliser used (Gg N); and FN is the fraction of N applied to vegetable industry (the only data found for this fraction is for horticulture/vegetable crops by State, Table 2)

Australian Vegetable Industry Estimate

National information on Australian vegetable production fertiliser use was not readily available. However, fertiliser rates for most vegetable crops are available in a Department of Agriculture study on farm gross margins in the NSW vegetable industry (Table 3). To make a preliminary estimate the on-farm fertiliser GHG emissions for the national Australian vegetable industry these fertiliser rates have been assumed for the whole country. The total fertiliser use was obtained by multiplying these rates by the national production area (Table 3). The quantity of nitrogen in each fertiliser was calculated and the direct GHG emissions were estimated using the emissions factor in Table 4.

The national estimate of emissions from fertiliser application is **195,556 t CO_2-e**.

Fuel Use

Fuel use was identified as one of the major costs and uses of energy by a committee of vegetable growers on the Mornington Peninsular [5].

The energy content of diesel, petrol and lubricants is readily available from a number of sources and its value is relatively uncontroversial [4]. The energy content and emission factors for various types of fuels are presented by the Department of Climate Change (NGAF, 2008) which can be used for estimating GHG emissions for Australian vegetable industry (Table 14).

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. Barber [5] found that vegetable production using full cultivation consumed 300 l/ha of diesel per crop, while minimum tillage reduced fuel use by 40 per cent, to 180 l/ha.

Australian Vegetable Industry Estimate

National information on Australian vegetable production fuel use was not readily available. However, fuel use required for most vegetable crops grown in NSW is available in a NSW Department of Agriculture study on farm gross margins (Data not shown). To make a preliminary estimate of the on-farm GHG emissions associated with fuel use for the national vegetable industry, these usage rates have been assumed applicable for the whole country. The total fuel use was obtained by multiplying these rates by the national production area.

An energy factor for diesel of 38.6 MJ L^{-1} has been assumed and an emissions factor of 69.8 kg CO_2-e GJ^{-1} (Table 14) was used to calculate the on-farm GHG emissions (Table 18).

Table 18. CO_2 emissions by machinery operations for various crops

Crop	Area (ha)	Production (kg)	Annual diesel use (kL)	Total CO_2 (tones/ha)	Total CO_2 (tonnes/kg)	Total CO_2 (tonnes)
Asparagus	1,302	5,609	548	1.13	0.26	1,478
Beans, french and runner	4,978	28,844	1,206	0.65	0.11	3,249
Beetroot	1,279	40,765	108	0.23	0.01	290
Broccoli	7,135	46,031	1,387	0.52	0.08	3,738
Cabbages	2,020	81,563	818	1.09	0.03	2,204
Capsicums (excluding chillies)	2,156	56,313	943	1.18	0.05	2,541
Carrots	5,715	271,464	769	0.36	0.01	2,071
Cauliflowers	3,580	69,793	354	0.27	0.01	953
Celery	991	48,542	240	0.65	0.01	647
Chillies (excluding capsicums)	163	1,957	39	0.65	0.05	106
Cucumbers	577	41,931	140	0.65	0.01	377
Green peas (processing shwf wt)	3,354	533	812	0.65	4.11	2,189
Green peas (Fresh market, pod weight)	277	15,232	67	0.65	0.01	181
Lettuces	10,011	271,251	3,487	0.94	0.03	9,396
Melon -Rock and cantaloupe	2,628	68,105	362	0.37	0.01	975
Melon –Water	4,421	136,861	1,074	0.65	0.02	2,895

Mushrooms	181	42,739	44	0.65	0.00	118
Onions	5,413	246,496	798	0.40	0.01	2,150
Potatoes	34,096	1,211,988	4,033	0.32	0.01	10,865
Pumpkins	5,968	102,505	406	0.18	0.01	1,094
Sweet corn	5,942	62,575	2,070	0.94	0.09	5,577
Tomatoes	7,293	296,035	3,013	1.11	0.03	8,118
Zucchini and button squash	2,438	23,704	672	0.74	0.08	1,809
National Total						**63,021**

R, D & E needs for on-farm emissions:

- Undertake an inventory of the range of irrigation practices used in the vegetable industry, and benchmark the best practices against the others growers and industries, 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.
- Develop an inventory of fertiliser practices in the vegetable industry.
- Measure the N_2O emissions from key vegetable farming systems.
- Evaluate through a literature review and incubation studies the evidence of the role of soil carbon on reducing or increasing N_2O emissions. Raising soil carbon levels is often mentioned as an important objective of the vegetable industry, therefore any possible negative impacts needs to be considered.
- Undertake research using laboratory and field techniques to better quantify the soil GHG emissions from vegetable production.
- Estimate fuel use in the vegetable industry.

III. Post-farm (downstream) greenhouse gas emissions

Transport of produce to market

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

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.

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 produce 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 that go into vegetable production is consumed more efficiently.

IV. Total Vegetable Industry Carbon Footprint Calculations

The life cycle of the vegetable industry can be divided into following components: (i) pre-farm CO_2 emissions, (ii) on-farm CO_2 emissions, and (iii) post-farm CO_2 emissions. The methods for estimating emissions for each of the components and as well as for total emissions are presented below.

Pre-Farm GHG emissions calculations

The pre-farm CO_2 emissions for the components of the Australian vegetable industry estimated in this study can be calculated from:

$$\mathbf{Pre_{GHG} = TF_{GHG} + TC_{GHG} + E(Irr)_{GHG} + E(Post)_{GHG} + F_{GHG}}$$

Where: Pre_{GHG} is the total pre-farm CO_2 emissions; TF_{GHG} is the total CO_2 emission due all types of fertilisers use; TC_{GHG} is the total CO_2 emission due all types of agrichemicals use; $E(Irr)_{GHG}$ is the total CO_2 emissions due to electrical use for irrigation; $E(Post)_{GHG}$ is the total CO_2 emissions due to electrical use for postharvest use; and F_{GHG} is the total CO_2 emissions due to fuel production.

The preliminary estimates for pre-farm CO_2-e emissions for the components above of the Australian vegetable industry that have been estimated in this study are:

$$81{,}362 + 6{,}375 + 534{,}860 + 155{,}000 + 10{,}834$$

$$\mathbf{= 788{,}431\ t\ CO_2\text{-}e\ year^{-1}}$$

Direct GHG emissions calculations

The pre-farm CO_2 emissions for the components of the Australian vegetable industry estimated in this study can be calculated from:

$$\mathbf{ON_{GHG} = SL_{GHG} + TM_{GHG}}$$

Where: SL_{GHG} is the GHG emission from soils (t CO_2-e); TM_{GHG} is GHG emission due to fuel use

The preliminary estimates for on-farm CO_2 emissions for the components above of the Australian vegetable industry that have been estimated in this study are:

$$195{,}556 + 63{,}021$$

$$\mathbf{= 258{,}577\ t\ CO_2\text{-e}\ year^{-1}}$$

Post-Farm GHG emissions calculations

No post-farm CO_2-e emissions for the components of the Australian vegetable industry have been estimated in this study.

Total GHG emissions calculations

Total greenhouse gas emission from vegetable industry can be calculated using:

$$\mathbf{T_{GHG} = PRE_{GHG} + ON_{GHG} + POS_{GHG}}$$

Where: T_{GHG} is the total pre-farm CO_2 emissions; ON_{GHG} is the total on-farm CO_2 emissions; and POS_{GHG} is the total post-farm CO_2 emissions.

The preliminary estimates for total CO_2-e emissions for the components above of the Australian vegetable industry that have been estimated in this study are:

$$\mathbf{788{,}431 + 258{,}577}$$

$$\mathbf{= 1{,}047{,}008\ t\ CO_2\text{-e}\ year^{-1}}$$

Comparison of Vegetable emissions with other industries

Comparisons between the carbon footprints in different industries has to be undertaken with great caution because the underlying assumptions and the components included can be very different.

From the GHG emissions estimated in this study, the greatest proportion of emissions are from electricity at 65 per cent (Fig. 2). This can be compared with a similar breakdown from an New Zealand irrigated dairy farm (Fig 3).

Agriculture is estimated to have contributed 87.9 $MtCO_2$-e in 2005 of which horticulture and the vegetable industry are estimated to have contributed approximately 1 MtCO2-e (1.1 per cent) and 0.6 MtCO2-e (0.7 per cent) respectively (see Discussion Paper 5). However these figures do not include the use of electricity and fuel used on farm which has been accounted for in our estimation. If electricity, fuel and fertilizer used on-farm is included then the estimated emissions from horticulture and the vegetable industry in 2005 are 5 and 3 MtCO2-e respectively.

The estimate from our study is approximately one-third this value. This illustrates the need to obtain more accurate information on the carbon footprint of the Australian vegetable industry, and horticultural industry in general.

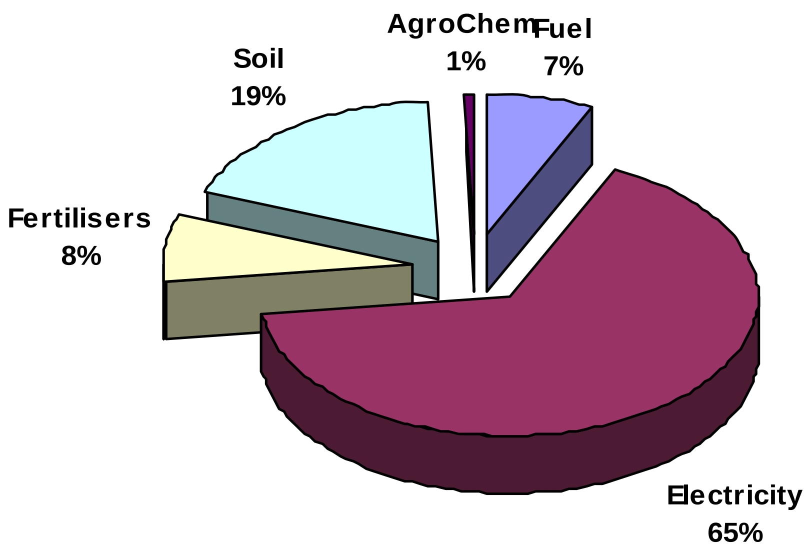


Figure 2 Proportion of green house gas emissions from the Australian vegetable industry.

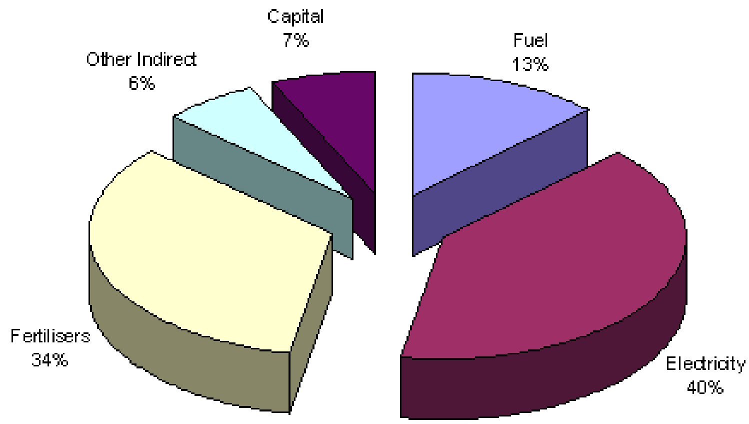


Figure 3 Proportion of Energy Inputs on the Average NZ Irrigated Dairy Farm

(http://www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/resource-management/total-energy-indicators-of-agricultural-stability/total-energy-indicators-of-agricultural-stability-01.htm)

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Appendix 1:

Direct Global Warming Potentials (mass basis) relative to CO_2 (for gases for which the lifetimes have been adequately characterised).*

Gas	Chemical formula	IPCC 1996 Global Warming Potential
Carbon dioxide	CO_2	1
Methane	CH_4	21
Nitrous oxide	N_2O	310
Hydrofluorocarbons HFCs		
HFC-23	CHF_3	11,700
HFC-32	CH_2F_2	650
HFC-41	CH_3F	150
HFC-43-10mee	$C_5H_2F_{10}$	1,300
HFC-125	C_2HF_5	2,800
HFC-134	$C_2H_2F_4$ (CHF_2CHF_2)	1,000
HFC-134a	$C_2H_2F_4$ (CH_2FCF_3)	1,300
HFC-143	$C_2H_3F_3$ (CHF_2CH_2F)	300
HFC-143a	$C_2H_3F_3$ (CF_3CH_3)	3,800
HFC-152a	$C_2H_4F_2$ (CH_3CHF_2)	140
HFC-227ea	C_3HF_7	2,900
HFC-236fa	$C_3H_2F_6$	6,300
HFC-245ca	$C_3H_3F_5$	560
Perfluorocarbons PFCs		
Perfluoromethane (tetrafluoromethane)	CF_4	6,500
Perfluoroethane (hexafluoroethane)	C_2F_6	9,200
Perfluoropropane	C_3F_8	7,000
Perfluorobutane	C_4F_{10}	7,000
Perfluorocyclobutane	c-C_4F_8	8,700
Perfluoropentane	C_5F_{12}	7,500
Perfluorohexane	C_6F_{14}	7,400
Sulphur hexafluoride	SF_6	23,900

* These GWP factors are those specified for calculating emissions under Kyoto accounting provisions.