Enhancing environmental sustainability in the processing potato industry

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Enhancing Environmental Sustainability in the Processing Potato Industry in Australia

Horticulture Australia Ltd (Project PT07060)

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HAL PROJECT PT07060 – FINAL REPORT

EXECUTIVE SUMMARY

A key strategy of the potato industry in Australia is to improve its competitiveness and environmental sustainability. In February 2008, Horticulture Australia Ltd. commissioned the Tasmanian Institute of Agricultural Research (TIAR) to examine the environmental footprint of the processing potato industry in Australia, from farm to factory gate. The specific aims were to:

- quantify inputs and outputs from the production of processed potatoes in units that can be easily compared to other industries.
- analyse production processes to identify opportunities for efficiency improvements, such as avoiding waste treatments and using fewer resources, while reducing financial costs.
- identify significant natural resource management and environmental sustainability issues facing the Processing Potato Industry in Australia.

The time and resources available to undertake the research were limited. As a consequence, it was not possible to undertake a comprehensive scientific analysis of the industry and its environmental footprint. Hence, the research presented here is preliminary in nature.

Three quarters of the total national potato crop is produced in three States - South Australia (30%), Tasmania (25%) and Victoria (21%) – with the balance of production occurring in Queensland and Western Australia. The total annual production of potatoes in Australia (fresh and processed) was 1,211,988 tonnes with an estimated farm gate value of $460.3 million and a gross value of $514.4 million in 2007. The total estimated area of potatoes grown in 2007 was 34,096 ha, with a national mean average yield of 36 t/ha.

We used two different scenarios to quantify and model the environmental footprint of the industry, based on different ways to assess the inputs and outputs to production. This approach allowed the identification of consistent trends associated with the actual production process, as opposed to those which arise more as an artefact of the method of analysis. The modelling involved the collection of information for seed potato grading and storage, and potato production from several States. Several potato case studies were undertaken: Tas 1 (processing, var. Russet Burbank), Tas 2 (processing var. Mac 1), Tas 3 (processing var Russet Burbank), Mallee (processing var. Russet Burbank), Lockyer Valley (processing, vars. Kennebec and Shepody). A preliminary examination of the environmental footprint of the onion and broccoli industries in Australia was also undertaken to provide a comparison to the processing potato industry, and to illustrate how the environmental footprint models can be used to compare and benchmark different horticultural industries.

A review of the environmental sustainability issues associated with the processing potato industry indicated concerns about the use of fertilizers and pesticides, energy use and greenhouse gas emissions, the management of natural resources, the conservation of biodiversity, and the impacts of climate change and variability. The significance of these environmental issues was examined as part of the environmental footprint modelling.

Our research showed that the processing potato industry can have a significant impact on soil, water and land resources. Soil conservation and sustainable land management are important challenges for the industry in all areas where potatoes are grown. Water conservation and the adoption of water use efficiency technologies are priorities for the industry and will help to reduce energy use and the costs of production.

Energy use and the emission of greenhouse gases (GHG) were a major focus of the environmental footprint modelling. The main emitters of GHG in potato growing were fertiliser (24.9-55.9% of emissions), diesel use (25.9-39.5%), agri-chemical use (3.5-8.9%), infrastructure (10.7-15.9%) and electricity (0-19.1%). This pattern was similar to the findings of research on the GHG emissions of potato production undertaken recently in New Zealand and the United Kingdom. On farm production of potatoes may produce in the order of 2.5% of the emissions of CO_2-equivalents from the Agriculture, Forestry and Fisheries sector at a State and Territory level. In comparison to other horticultural industries such as onions and broccoli, the potato industry is likely to be one of the main emitters of GHG. The relatively high intensity of production of potatoes means that its environmental impact is likely to be disproportionate to the area of land under cultivation. The industry needs to better understand its relative contribution to GHG emissions and will need to be proactive in reducing emissions. Some of the methods we outline to reduce emissions have the added advantage of reducing the costs of production to growers and processors.

Recommendations

Our research identified a range of opportunities for the industry to enhance its production efficiency and environmental performance and made a series of recommendations, including:

- *Greenhouse gas emissions*

The industry needs to better understand its relative contribution to GHG emissions, and should gather actual site-specific information with regard to N_2O emissions in different regions and soil types, and from the use of different fertilisers and fertiliser use practices, to more accurately determine GHG emissions for differing production strategies. It is vital for the industry to be prepared for the Carbon Pollution Reduction Scheme (CPRS) and opportunities for carbon trading, should it be included when agriculture enters the CPRS in 2015 or beyond. Nevertheless, the industry will incur carbon costs through fuel, fertiliser and chemical and other input costs from 1 January 2010, and needs to develop strategies and practices to accommodate and respond to cost impositions from that date. This will mean developing and adopting practices that reduce GHG emissions, and will be facilitated by modelling GHG emissions for a diversity of locations and production systems.

- *Energy use*

The adoption of methods to reduce energy will reduce GHG emissions and be of financial benefit to growers and the processing potato industry in Australia. In our study, diesel made up a significant proportion of the energy used on-farm. There are opportunities for reduced diesel use in the industry. The development of controlled-traffic systems will assist growers to reduce energy use and improve environmental performance. Investigating the use of alternative fuels (e.g. biodiesel) has merit.

One of the main contributors to electricity use in the growing of potatoes is the pumping of irrigation water. Efficiencies in water use will translate into energy efficiency. From a GHG perspective, the reduction in electricity use is more important in States such as Victoria and Queensland where electricity generation is predominately through the burning of coal.

Nitrogen fertiliser represents a major energy input, and improvement in nitrogen use efficiency will contribute to reduced energy consumption by the industry, as well as contribute to reduced GHG emissions, particularly through lower N_2O emissions

There is an opportunity to develop and implement an education campaign for growers, and the industry more widely, on fuel efficiency in agronomic operations.

- *Nutrient management*

Improved efficiency of nutrient use will have both environmental and financial benefits to growers. New R, D & E is required to improve the efficiency of nutrient use on farms. Ways to improve efficiency include the demonstration of decision support tools such as the Potato Calculator to better match nutrient application, particularly of nitrogen, with crop demand, the identification and use of fertilisers with lower capacity to contribute to N_2O emissions or leaching and run-off, and the promotion of methods of managing nutrients left over in crop residues and soil after crop harvest. Whole system research is indicated, with particular emphasis on aspects that enhance nutrient use efficiency and recovery through the crop rotation cycle, as distinct from within single crops.

- *Water use efficiency*

Growers will face increasing pressure to improve water use efficiency across Australia. There are opportunities for more efficient use of water through the adoption of more efficient irrigation systems and irrigation scheduling techniques, and perhaps through the use of potato varieties that require less water (as in our case study Tas 2). Additional education and extension support is necessary to provide growers with information on the benefits of particular irrigation systems, and training in the use of irrigation scheduling tools and more efficient technologies. Research into precision irrigation in the vegetable industry has a vital role to play in water conservation, and enhancing water savings and associated cost savings to growers.

- *Soil management*

Soil management is critical to the sustainability of the potato industry. Conventional production practices can lead to significant structural degradation, loss of soil carbon and soil erosion with consequent off-site nutrient contamination. There is a need for the industry to continue to improve soil management practices and to test new practices such as controlled traffic. The industry would benefit from a better understanding of the dynamics of soil carbon and the most efficient methods of maintaining or increasing soil carbon.

- *Pesticide use*

Although pesticides represent a relatively minor component of GHG emissions, there are opportunities to reduce pesticide use in the industry. While the processing industry is dominated by the variety Russet Burbank, there are advantages in utilising more disease resistant varieties (as in Tas 2) that would be expected to reduce pesticide use. There are further opportunities to reduce agri-chemical use by supporting new research that improves the quality of disease forecasting. Similarly, it is important to maintain a strong biosecurity capability at a national and regional level to help prevent the entry of pathogens and pests that require increased pesticide applications.

- *Adaptation to climate change*

Adaptation responses to climate change in horticulture will need to take a flexible, risk-based approach that incorporates future uncertainty and provides strategies that will be able to cope with a range of possible local climate changes. Initial efforts in preparing adaptation strategies should focus on equipping primary producers with alternative adaptation options suitable for the range of uncertain future climate changes and the capacity to evaluate and implement these as needed. The adaptation responses will need to incorporate many of the points mentioned above, and include approaches and strategies that support rather than diminish practices designed to limit the environmental footprint of the industry. It would be expected that many changes would be focused in modeling of agricultural systems and their carbon economy and adaptive agronomy, but larger researchable issues may emerge, especially if the industry expanded into or partially relocated to new production areas.

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CAVEAT

The views and interpretations expressed in this report are those of the authors and should not be attributed to Horticulture Australia or any other organisation associated with the project. Any comments should be directed to:

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1. INTRODUCTION

The Australian processing potato industry, in conjunction with Horticulture Australia Ltd. (HAL) and on behalf of the Commonwealth Government, have invested over $8 million dollars into research and development since 2001. One of the major strategies of the Processing Potato Industry in 2008 is to improve industry competitiveness, which includes enhancing environmental sustainability. The industry acknowledges that producers, consumers and government organisations are becoming more aware of environmental costs and the industry recognises the benefits of positioning themselves to address key environmental issues. In February 2008, HAL commissioned the present study ‘Enhancing environmental sustainability in the processing potato industry’ and the Tasmanian Institute of Agricultural Research (TIAR) was subsequently awarded the contract to undertake the research.

1.1 Purpose of the study

The purpose of the study is to:

- quantify inputs and outputs from the production of processed potatoes in units that can be easily compared to other industries.
- analyse production processes to identify opportunities for efficiency improvements, such as avoiding waste treatments and using fewer resources, while reducing financial costs.
- identify significant natural resource management and environmental sustainability issues facing the Processing Potato Industry in Australia.

One aim of the project is to identify the areas of immediate concern and long term issues where industry environmental efforts would be best directed to maximise future investment. As part of the research, opportunities for advancing environmental sustainability through new partnerships with traditional and non-traditional third party funding bodies were considered.

It should be noted that the time and resources available to undertake the research were limited. As a consequence, it was not possible to obtain all of the data sets and information for the processing potato industry across Australia required to undertake a comprehensive scientific analysis of the industry and its environmental footprint. Rather, the study is preliminary in nature, and the findings should be considered as indicative of the trends and major environmental issues facing the industry. Notwithstanding these limitations, this is the first environmental footprint research of its kind undertaken for an agricultural industry in Australia, and we believe that Horticulture Australia should be acknowledged for its initiative in this regard.

In 2008, the United Nations Year of the Potato, it is timely that the processing potato industry take stock of its environmental performance and position itself as a leader in the sustainability of the horticultural industries, and as a leading environmental steward of the agricultural landscapes in which it operates.

1.2 Challenge of environmental sustainability

Australia's agriculture sector has a strong history of innovation and dynamism. It forms a significant part of the Australia economy, makes a substantial contribution to the national export performance, and is a mainstay of many rural and regional economies. Agricultural businesses have generally been resilient in the face of increasing competition, volatile commodity prices and the vagaries of uncertain climate. However, it is widely recognised that the operating environment for agriculture is changing rapidly and that change will be a long term constant for the sector.

There are a number of key drivers for improving the environmental sustainability and performance of primary industries. First, community expectations have changed. The Australian community and governments now insist that agricultural production does not negatively impact on the surrounding environment and the natural resource base. Second, the price of scarce natural resources and other inputs to production have changed. Rising costs of farm production such as energy inputs, fuel and fertiliser emphasise the need for industry-wide and farm-level productivity and efficiency gains that also enhance environmental performance. Public policy reforms in relation to water access, use and pricing to help conserve scarce water resources and protect environmental flows may impact significantly on production options, profitability and agricultural land use. Third, scientific knowledge of the 'forcers' of climate have changed. Public concerns about climate change and the need to significantly reduce greenhouse gas emissions are beginning to reshape the concepts of best practice in environmental management giving emphasis to production practices that eliminate or significantly reduce energy consumption and greenhouse gas emissions across production systems. Good agricultural land management is seen as a prerequisite for reducing environmental degradation and improving sustainability as well as underpinning farm profitability.

The Australian horticulture industry has taken up the challenge of environmental sustainability. It recognises that environmental sustainability is a priority, and that natural resources such as soil and water are a foundation of horticultural production (HAL 2008) (Figure 2.2). The industry has initiated and expanded a national program called 'Horticulture for Tomorrow'. The program is part of a five-year environmental vision for horticulture, developed in collaboration with the industry:

"By 2010, Australian Horticulture will have embraced a systematic approach to environmental management that underpins the economic, social and environmental sustainability of the industry." (HAL vision 2006)

The horticulture industry has developed a NRM Strategy to address:

- global matters such as greenhouse and climate change, and market access
- national issues such as the COAG Water Reforms and food safety
- Australian State or regional concerns such as environmental regulations affecting water allocations or native vegetation management
- local or property level management issues such as pest and disease control, nutrients and soil health. (HAL 2006)

The Horticulture Australia NRM Strategy is designed to enable horticultural industries to deal with environmental matters in the economic and social context in which growers operate. The critical natural resource management issues identified by the industry include water, soil, air, native biodiversity, biosecurity, changing land use, capacity building, NRM planning and sustainable business operations (HAL 2006).

1.3 Challenge of climate change and variability

Climate change and climate variability pose enormous challenges to agriculture. Australia has one of the most variable climates in the world and the agricultural sector has attempted to adapt to uncertain climate and climate extremes such as a drought that may dramatically affect production. New scientific understanding of climate change and variability, and the types of growing environments that the agricultural sector appears likely to experience over the coming decades present unprecedented challenges for management.

Globally, Australia is ranked around 19th in terms of CO_2 emissions and around 3rd in terms of emissions on a per capita basis (Anon 2008a). In 2006, Australia's net greenhouse gas (GHG) emissions from all sectors of the economy equated to some 576.0 million tonnes of CO_2 equivalents (Mt CO_2-e), with the greatest emissions from the electricity gas and water sector (35.5% of national emissions) (Anon 2008a). The agriculture, fish and forestry sector was second highest with 32.7% of national emissions (136 Mt CO_2-e) (Figure 2.4). Emissions in this sector were down 39.9% from 1990, due principally to a change in land use practices (e.g. restrictions on broad scale clearing of native vegetation) (Anon 2008a).

The Australian government recently announced a policy commitment to introduce a Carbon Pollution Reduction Scheme (CPRS) to help address climate change and reduce greenhouse gas emissions (Commonwealth of Australia 2008). The Scheme will, for the first time in Australia, place a limit or cap on the amount of carbon pollution industry can emit. The CPRS will require affected businesses and industry to buy a 'pollution permit' for each tonne of carbon they contribute to the atmosphere. The Scheme will concentrate on the biggest polluters and is proposed to commence in 2010.

The government does not consider it practical at this stage to include agriculture emissions in the trading scheme at commencement (Commonwealth of Australia 2008). However, it is considered desirable to have maximal coverage of the major carbon polluters in the CPRS. Hence, it would seem merely a matter of time before the agricultural sector in brought into the Scheme. At present, a timeline of 2015 for inclusion is foreshadowed. Clearly, it will be to the commercial and market advantage of industries to quantify their greenhouse gases emissions, and for those industries emitting significant volumes of greenhouse gases to comprehensively address this aspect of their production process and distribution network.

Climate change forecasts

Climate change forecasts for Australia have been developed and revised as new data become available. The most recent climate change forecasts for Australia are based on international climate change research including conclusions from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), and build on a large body of climate research that has been undertaken for the Australian region in recent years (CSIRO and BoM 2007) (Figures 1.1 & 1.2).

The best estimate of annual warming over Australia by 2030 relative to the climate of 1990 is approximately 1.0º C, with warming of around 0.7-0.9º C in coastal areas and 1-1.2º C inland (Fig. 1.1). Mean warming in winter is a little less than in the other seasons (CSIRO and BoM 2007). Best estimates of annual precipitation indicate little change in the far north of Australia and decreases of 2% to 5% elsewhere. Decreases of around 5% prevail in winter and spring, particularly in the south-west of Australia where they reach 10%. In summer and autumn, decreases in precipitation are smaller and there are slight increases in eastern Australia. The range of precipitation change in 2030 is large. Annually averaged, the range is around -10% to +5% in northern areas and -10% to little change in southern areas of Australia. Decreases in rainfall are more consistently predicted for southern areas compared to northern areas (Fig. 1.1) (CSIRO and BoM 2007).

Overall, the broad pattern of climate projections reported for Australia indicate likely rainfall reductions in the temperate and sub-tropical regions. Even where rainfall is projected to decrease, precipitation intensity is projected to increase with longer periods between rainfall events (Fig. 1.1) (CSIRO and BoM 2007).

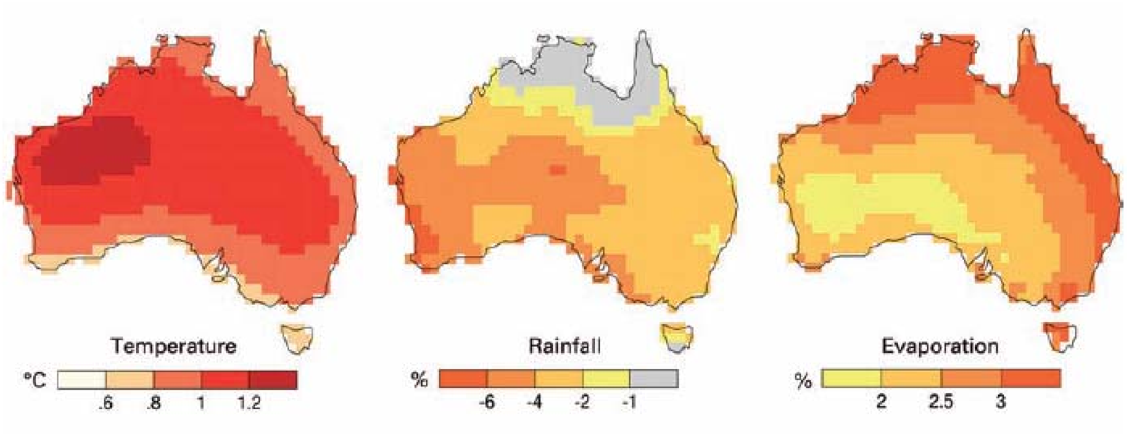

Figure 1.1 Median projected changes in annual-average temperature, rainfall and potential evaporation by 2030, relative to 1990, for the mid-range low emissions scenario (Australian Government 2008).

The climate forecasts suggest that potato growing regions in Tasmania, Victoria and Western Australia, in particular, will be exposed to increases in air temperature and decreases in precipitation. This will have implications for the timing and duration of the growing season, soil temperature and moisture, and irrigation scheduling. Detailed agronomic studies and the monitoring of crops will be required to adapt potato production to changes in climate.

Climate variability

The Australian government's CSIRO and Bureau of Meteorology published a scientific report in July 2008 examining the likely impact of climate change on exceptional climatic events in Australia such as the nature and frequency of exceptionally hot years, exceptionally low rainfall years, and exceptionally low soil moisture years. This research is part of a national study of drought policy that the Australian government is conducting as it reviews its policy disposition on drought and the definition of 'Exceptional Circumstances' that is used to trigger drought assistance and support as a short term measure to help farmers prepare for, manage and recover from drought.

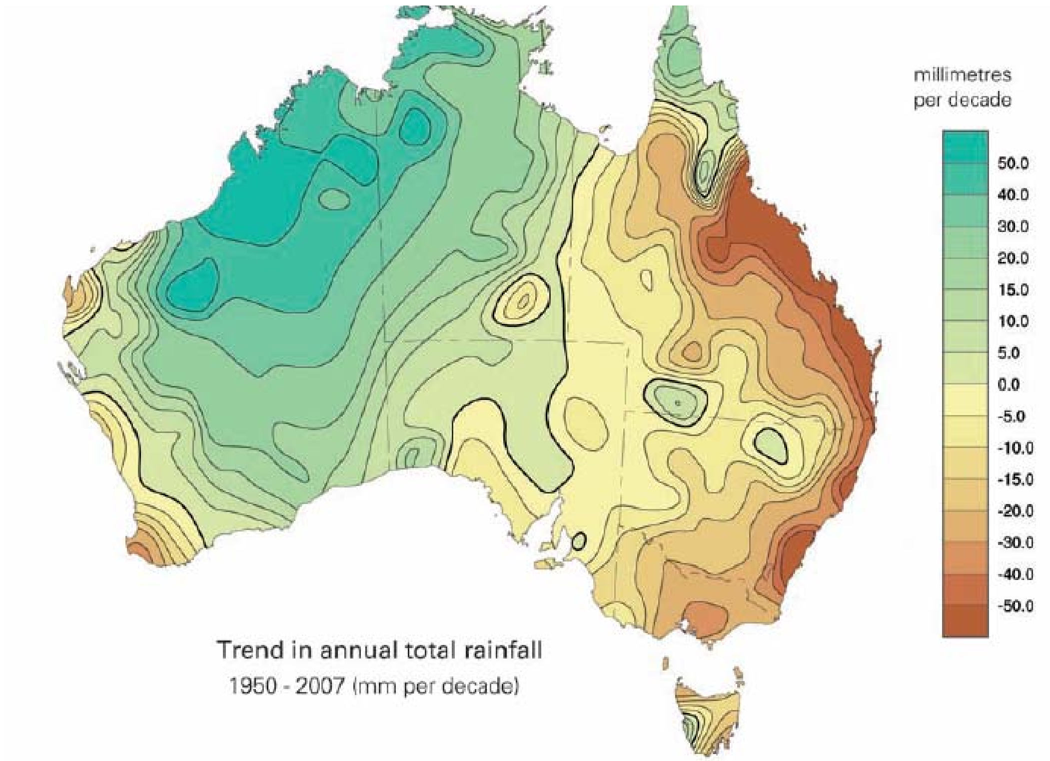

Figure 1.2 Regional trends in annual total rainfall for the period 1950 – 2007 (mm per decade) (Australian Government 2008).

Since 1950, the average annual maximum temperature and annual mean temperature have increased significantly while the annual minimum temperature and annual total rainfall have decreased in Victoria and Tasmania (Figure 1.2). The data show relatively strong warming and drying trends. For the period 1968-2007, the land area experiencing exceptionally hot years increased markedly to over 10% of the region, on average.

The predicted trends over the next three decades are amplified significantly in Victoria and Tasmania. For example, for the period 1900-2007 the average land area experiencing exceptionally hot years was 4.6% and the average return period for hot years was 21.8 years. This compares to 76.1% and 1 year, on average, respectively that are predicted for the period 2010-2040. These predictions suggest major changes from the average ambient air temperature patterns experienced in southern Australia during the last century. The report also notes that projected decreases in annual average rainfall are likely to result in fewer exceptionally wet years and more exceptionally dry years (Figure 1.2).

Potato growing regions in southern Australia will be most impacted by the variations in climate predicted by the CSIRO and BOM study as the frequency of exceptionally hot years and low rainfall years increase and become far more common. The availability of water for irrigation will be a significant issue at a property and catchment level.

Climate change adaptation

The Intergovernmental Panel on Climate Change Fourth Assessment Report (Hennessy *et al.* 2007; IPCC 2007) concluded that the agriculture sector in Australia is particularly vulnerable to climate changes, with potential negative impacts on the amount of produce, quality of produce, reliability of production and on the natural resource base on which agriculture depends. This vulnerability requires high levels of adaptive responses.

To explore the issues and opportunities associated with climate change and adaptation in the agricultural sector in Australia, CSIRO have recently published a synthetic report covering many industries (Stokes and Howden 2008). An analysis of the horticultural industry suggests that it may have considerable exposure to various climate-related impacts. For example, the industry is based in a number of regions across strong climate gradients in Australia. The industry produces high value products from small areas and production techniques may have a high level of management input that is often aimed at ameliorating climate risks (e.g. via irrigation). A number of horticulture industries have significant cold-temperature requirements that are likely to be at risk as local and regional climate changes.

Webb et al. (2008) discussed the potential implications of climate change for major horticulture industries such as the potato industry and proposed options for adaptation focusing on issues of site selection, crop management, varietal selection, water, changing levels of CO_2, pest and disease management and risk, consumer impacts, and the use of existing knowledge. To manage the risks associated with reduced water supply and increases in water demand it will be necessary to develop suitable hydrological models. Regional climate projections can be used as input to catchment-scale hydrological models to assess the effects of water availability on present and future production and the sites most suited to production. It will be necessary to continue improvements in irrigation technology used in the processing potato industry. The effect of enriched CO_2 on crop water-use will need to be better understood when looking at the water requirements for potato production (Webb et al. 2008). And it is recognized that industry adaptation to changes in the risk of pest and diseases will need to be addressed at a regional level (TQA 2008).

2. PROFILE OF THE PROCESSING POTATO INDUSTRY IN AUSTRALIA

2.1 Introduction

The potato industry is an important part of the horticultural industry in Australia. Potato production occurs mainly in the southern regions of the continent where the climate is more conducive to potato growing. The main potato production areas occur in South Australia (North Adelaide Hills, Riverland, Pinnaroo and Mt. Gambier), Tasmania (north coast), Victoria (Portland, Colac, Ballarat, outer Melbourne and Warragul) and New South Wales (Riverina, Crookwell and New England). Other areas of production include Perth, Manjimup and Albany in Western Australia and the Atherton Tablelands, Lockyer Valley and Bundaberg in Queensland.

Three quarters of the total national potato crop is produced in three States - South Australia (30%), Tasmania (25%) and Victoria (21%) – with the balance of production occurring in Queensland and Western Australia. Tasmania and Victoria were the dominant potato producing states in Australia until recently (Anon. 2005).

The potato industry in New South Wales, Victoria and Tasmania is dominated by the processing industry, whereas potato production in South Australia, Western Australia and to a lesser extent in Queensland is dominated by fresh market production.

The total annual production of potatoes in Australia (fresh and processed) in 2007 was 1,211,988 tonnes with an estimated farm gate value of $460.3 million and a gross value of $514.4 million (Anon. 2008ab). The total estimated area of potatoes grown in 2007 was 34,096 ha, giving a national mean average yield of 36 t/ha (Anon. 2008a) (Table 2.1).

Although average yield increased from 35 t/ha in 2006 to 36 t/ha in 2007, a slight decrease was reported for total production and the total area of potatoes grown. Total potato production decreased by 3% in 2007 with a total Australian potato production of 1,249,605 t in 2006 compared to 1,211,988 t in 2007. The total area of potatoes grown in Australia decreased by

1,172 ha with a total estimated potato growing area in 2006 of 35 268 ha compared to 34,096 ha in 2007.

Table 2.1 Production of potatoes (tonnes), area (hectares), and yield (t/ha) for all purposes (fresh and processed) in different states of Australia, year ending 30 June 2007 (Anon. 2008ab).

	NSW	VIC	QLD	SA	WA	TAS	AUST
Production (t) [1]	122729	256 478	88 083	364 255	78 697	301 747	1211 988
Area (ha) [1]	^4 568	8 098	3 498	9 403	^1 911	6 618	34 096
Yield (t/ha) [1]	27	32	25	39	41	46	36
Gross Value ($m) [2]	50.3	109.4	55.2	178.6	38.3	82.5	514.4
Local Value ($m) [2]	43.7	94.1	46.0	161.5	33.6	81.3	460.3
Gross Unit Value ($/t) [2]	410	426	627	490	487	273	424

NSW = New South Wales, VIC = Victoria, SA = South Australia, WA = Western Australia, TAS = Tasmania and AUST = Australia
^estimates has a relative standard error of 10% to less than 25% and should be used with caution.
[1] Source: ABS, Agricultural Commodities, Australia Cat. No. 7121.0 (year ending 30 June 2007)
[2] Source: ABS, value of Agricultural Commodities produced, Australia Cat. No. 7503.0 (year ending 30 June 2007).

The total production, area grown, yield and value of potatoes for each state of Australia for year ending June 2006 is listed in Table 2.2. The Australian processing potato industry and fresh potato market industry produced 730,288 t and 519,317 t, respectively, with similar production areas of 18,196 ha and 17,072 ha, respectively. The average yield of processed potato (40 t/ha) was higher than that of the yield of fresh potato (30 t/ha) (Table 2.2).

In Tasmania, around 80% of potatoes are grown for the processing industry, with an emphasis on frozen French fry production (Kirkwood 2007). The remainder of the Tasmanian potato industry is comprised of 10% fresh market and 10% seed potato (Kirkwood 2007). In 2004 approximately 25% of the potato industry in NSW was sold as processing potato, with other market shares including 72% fresh potato market and 3% used for seed (Anon. 2004). A survey conducted in 2006 of 74 Tasmanian and 29 Victorian potato growers showed the majority of potato produced in Tasmania and Ballarat, Victoria is used for the French fry market, 91% and 57%, respectively (Sparrow L. and Crump N. unpublished data).

The Australian potato processing industry is dominated by two frozen processing companies: McCains Food and Simplot Pty. Ltd. Potato processing plants are located in Victoria, Tasmania and South Australia. The majority of potato production grown for the processing industry in Australia is grown under contract for the processing companies (Anon. 2006). Over the past 10 years the production of potato in Australia has slowly declined due to increased production costs and the threat of competition from low cost international produce (Anon. 2006). The industry has recently faced a substantial increase in costs due to rising fuel and fertiliser costs (Anon. 2008e).

A survey conducted in 2006 of 74 Tasmanian and 29 Victoria potato growers indicated the average property size of potato growers surveyed was 101-200 ha (36%) and 401-1000 ha (41%) for Tasmanian and Victorian potato growers, respectively. The average area planted with potato by Tasmanian and Victorian potato farmers surveyed in 2006 was between 11-20 ha (37%) and between 51-100 ha (33%), respectively, with the percentage of the total farm planted with potato between 6-10 % for both Tasmania (37%) and Ballarat, Victoria (35%) (Sparrow L. and Crump N. unpublished data).

The main potato varieties grown in South Australia, Tasmanian and Victoria for the potato processing industry include Russet Burbank, Ranger Russet and Shepody (Kirkwood 2007, Anon. 2008f, Anon. 2008g). In 2006 a survey of potato growers from Tasmanian and Ballarat, Victoria indicated the main cultivar grown in Tasmania was Russet Burbank (77%) followed by Ranger Russet (11%), and mixtures of cultivars including Shepody (Sparrow L. and Crump N. unpublished data). The main potato processing variety grown in NSW is Shepody (Anon. 2004).

Export markets for potato (excluding seed potato) produced in South Australia include United Arab Emirates, Indonesia, Singapore and Hong Kong (Anon. 2008c). Transportation costs can be prohibitive for exporting potatoes to the mainland and internationally from Tasmania. However, there are reported yield advantages of utilising seed grown in southern regions for ware crops in northern regions (Kirkwood 2007).

Table 2.2 Production of potatoes (tonnes), area (hectares), gross value, local value, gross unit (Australia dollars) for fresh and processed potato in different states of Australia ending 30 June 2006 (Anon. 2008cd).

	NSW	VIC	QLD	SA	WA	TAS	AUST
Processing							
Production (t) [1]	83 393	180 291	41 210	125 987	34 381	266 026	730 288
Area (ha) [1]	2 695	4 803	1 481	2 795	900	5 522	18 196
Yield (t/ha) [1]	31	38	28	45	38	48	40
Fresh market							
Production (t) [1]	48 541	109 044	52 379	231 784	55 040	22 529	519 317
Area (ha) [1]	2 451	3 737	2 158	6 690	1 249	788	17 072
Yield (t/ha) [1]	20	29	24	37	44	29	30
Processing and fresh							
Gross Value ($m)[2]	49.3	117.1	46.9	135.9	40.5	73.7	463.5
Local Value ($m)[2]	41.4	102.4	39.1	115.9	34.8	72.3	406.0
Gross Unit Value ($/t) [2]	377	405	502	380	453	256	371

NSW = New South Wales, VIC = Victoria, SA = South Australia, WA = Western Australia, TAS = Tasmania and AUST = Australia
^estimates has a relative standard error of 10% to less than 25% and should be used with caution.
[1] Source: ABS, Agricultural Commodities, Australia Cat. No. 7121.0 (year ending 30 June 2006)
[2] Source: ABS, Value of Agricultural Commodities Produced. Australia. Cat. No. 7503.0 (year ending 30 June 2006).

2.2 The potato production cycle

Modelling the environmental footprint of the processing potato industry requires detailed information on the major and different components involved in the production of potato crops for the industry. Given the limited time available for the present study it was not possible to obtain detailed information about the potato production cycle from all of the potato growing regions in Australia. Rather, the description of the production cycle presented here is based to a large extent on data available for Tasmania, South Australia and Queensland. Hence, this outline is indicative of the potato production cycle observed across Australia, and variations to the cycle will occur across States and regions. The information presented here informs the model development and modelling of the environmental footprint of the processing potato industry presented in Section 4, below.

The majority of potato production in Australia uses certified seed as planting stock for commercial crops. Commercial crops are also referred to as ‘ware crops’ and defined as potato crop grown specifically to be harvested for the fresh market or the processing industry. Vegetative propagation is the usual method of propagating potato, with tubers planted as cut seed or as whole seed. Vegetative propagation can be problematic to the potato industry due to soil-borne diseases, the need to maintain cultivar purity, tubers acting as a pathogen host and potential disease transmission between healthy, and diseased tubers during seed cutting. In addition the cut surface of a seed piece can enable external pathogens to enter the wound site. Certified seed crops are grown over consecutive growing seasons to increase the volume of seed production, minimise the occurrence of disease and maintain trueness of type and minimise defects. The production of potato crops consists of seed production and ware production with agronomic practices for pre-planting, planting, crop growth, harvest and storage.

Seed production

In Australia the seed potato certification scheme is governed by the National Standards for Certification of Seed Potato. In 2001 five separate state-based standards were replaced by the National Standards and provide national compliance for a uniform minimum standard for defects, disease and trueness to type. The seed certification scheme is voluntary and is overseen by the Seed Potato Advisory Group (SPAG), a sub-committee of AUSVEG. The establishment of the National Standard across Australian seed production has enabled improvements in many states compared to traditional seed certification schemes. Seed certification schemes in Australia are managed by state-based government departments. For example, seed schemes are managed by the Department of Agriculture and Food in Western Australia (DAFWA, Perth), VICSPA accredited mini-tuber facilities and laboratories are located in Victoria (Department of Primary Industries, Toolangi) Tasmania (Tasmanian Institute of Agriculture Research, Department of Primary Industries and Water, Devonport), New South Wales (D Carter, Crookwell) and South

Australia (Solan Pty. Ltd., Waikerie). The seed crop is certified if the incidence of disease is below the threshold set in the National Standard.

The seed scheme starts with tissue culture and mini-tuber production. Tissue cultured plantlets are maintained at an accredited mini-tuber facility mentioned above. Plantlets are initially obtained in tissue culture by removal of an apical meristem and 1-3 leaf primordia for a potato plant or tuber sprout. This meristematic material when grown *in vitro* on defined media produces the plantlet. Plantlets of seed lines are maintained in tissue culture by cutting segments of the plantlet including a node and leaf and placing into new sterilised media at approximately three week intervals. To prepare for mini-tuber production this process is repeated several times to provide sufficient numbers of plantlets. For mini-tuber production, plantlets are transplanted at high density into beds (or boxes) and grown in a controlled and protected environment. Mini-tubers are harvested when approximately 1.3 to 5.1 cm in size. A rigorous testing, inspection and hygiene regime is used to prevent infection of plants by pathogens. Due to the high cost of mini-tubers, potato producers generally purchase a limited number of mini-tubers to plant as starting seed stock and then multiply the number of tubers over a limited number of consecutive seasons, until there is sufficient tubers produced at sufficiently low unit price for planting of ware crops.

Production of seed potato involves planting of mini-tubers and growing seed crops over three to five consecutive seasons or generations (G). Seed is usually grown from G1 to G4, and occasionally G5. However, one processing company in Tasmania requires growers to cease seed production at G3 to further minimise the risk of entry of pathogens. Conversely other schemes such as that in Western Australia seed allows up to G5. A survey of potato growers survey in 2006 indicated the majority of potato growers in Tasmania (96%) and Ballarat, Victoria (97%) use certified seed potato as planting material for ware crops. The remainder of growers surveyed were uncertain of the origin of seed used in potato production during 2005/06. Tasmanian growers mainly sourced their seed through a processing company (59%) and for growers in Ballarat, Victoria the main source of seed was from a seed grower (72%). In Tasmania, 32% of growers sourced seed from a seed grower (Sparrow L. and Crump N. unpublished data).

During the growing season two visual field inspections are conducted on each seed crop by seed certification officers. The first inspection occurs around row closure and the second inspection occurs prior to crop maturation and before top removal. The National Standard requires fields to be free of potato for at least five years prior to planting crops of G1-G3, and at least three years for G4-G5 to reduce the risk of pathogens and 'volunteer' potatoes entering the seed crop. Each generation is given a 1-3 rating according to tolerances specified for virus disease, foreign cultivar, total diseased plants and other diseases. Generally a field rating of 3 excludes that crop from being multiplied further for seed certification. Tubers are also visually inspected after harvest. Approximately 200 tubers are collected from bulk trucks or containers and visually inspected for damage and defects, various disease and nematode. Maximum tolerances are set at 2% for all disease, insect damage and tuber defects. A rating of 'A' is given where seed meets set tolerance levels (Anon. 2001). Seed is required to be stored under conditions approved by inspectors of a certifying authority.

Crop rotation and pre-planting

A crop rotation of 5 or more years is optimal for potato production. A potato grower survey conducted in 2006 in Tasmanian and Ballarat, Victorian found that the majority of growers of ware crop surveyed rested their field from between 4-10 years from potato production. One grower in the Tasmanian survey reported an interval of up to 11 years between potato crops, while one Victorian potato grower reported intervals as short as three years between potato crops. Most potato growers rested their fields from potato crops for 5 years prior to planting another potato crop. The number of years that growers maintained pasture as part of their rotations ranged from 0-10 years. Crops such as poppy, cereal, pyrethrum and canola were also grown on rotation with potatoes. In Tasmania and Ballarat, 'volunteer' potatoes were usually controlled using herbicide and grazing (Sparrow L. and Crump N. unpublished data).

Field preparation occurs one to six months prior to planting a potato crop. In 2006, results of a potato grower survey showed the majority of potato growers for Tasmania (61%) and Ballarat (72%) started cultivating their fields for a subsequent potato crop between one-two months prior to planting. Some Tasmanian growers (8%) started ground preparation at least six months prior to planting potato (Sparrow L. and Crump N. unpublished). In Tasmania typical land preparation for a potato crop includes pre-cultivation weed control with glyphosate (1 spray, 3 l/ha) and dicamba (1 spray, 250 ml/ha) and land cultivation consisting of mouldboard ploughing (1 pass), tyne cultivations (2 passes), roterra (1 pass) and agrow plough (1 pass). Typical pre-spread fertiliser application includes superphosphate (1t/ha) (Anon. 2008e). Weed control for pre-cultivation typically consists of applications of glyphosphate (750 g/L) at 3 L/ha and dicamba (200 g/L) at 0.25 L/ha (Chris Russell, Simplot Australia and Les Murdoch McCain Foods Australia, personal communication).

Based on a 2006 survey of Tasmanian and Ballarat potato growers, 82% of the seed potato planted in Tasmania was cut into seed pieces prior to planting with the remainder of seed planted as a combination of cut and whole seed (18%). Cutting the seed into pieces provides additional seed pieces for planting. A total of 66% potato growers in Ballarat planted a combination of cut and whole seed with 34% using cut seed (Sparrow L. and Crump N. unpublished data).

Planting

In Australia planting time of potato crops is governed by weather conditions, expected harvest date and the probability of frosts in cooler regions of the country. The majority of planting of processing potato crops in Tasmania occurs between mid September and mid November. Cut tubers are loaded onto bulk trucks and transported to designated fields for planting. Mechanical planters are used to plant cut or whole seed pieces within furrows. In addition to creating the furrows the tractor also tows the mechanical planter in the field. A 2-row planter operates at a speed of 1 ha/hr. Planting requires one person to drive the tractor and one person operating the planter to ensure the cups of the planter contain one seed piece per cup. This is necessary to ensure correct planting density is achieved. The seed planting rate is approximately 2.7 t/ha. The furrow is then moulded with the seed piece ideally planted 150-200mm below the top of the mould. At planting, typical fertiliser application includes 11:12:19 NPK (~1.5-2 t/ha), variations of fertiliser application include 8:16:8 NPK (~2.0-2.2 t/ha). Fungicide (e.g. azoxystrobin) may be applied in the furrow at planting.

Crop growth

Fertiliser application during growth of a typical potato crop includes a side dressing of Urea (46% N) (125 kg/ha) and muriate of potash (50% K) (125 kg/ha). A typical irrigation regime of a potato crop requires approximately 4.5 ML/ha (400mm) with an average of 16 passes at 30-35 mm per pass. In Tasmania, potato industry representatives estimate approximately 70% of irrigation water is applied by travelling gun irrigator and 30% applied by centre pivots and lateral move irrigators. In 2006, a grower survey of Tasmanian and Ballarat potato growers indicated the predominant irrigation method in potato fields in Tasmania during 2005/06 occurred with travelling gun irrigator (61%), followed by a combination of the travelling gun irrigator and other irrigation method (not specified) (32%). Irrigation systems involving centre pivots and linear move irrigators were used by around 5% of Tasmanian potato growers. The number of irrigations applied per season ranged between 4-15 times, with the majority of growers in Tasmania applying irrigation water between 11-15 times (51%) during the 2005/06 season. The majority of Ballarat growers applied irrigation water more than 15 times (66%) during the growing season. Scheduling of irrigation was predominately based on visual inspection. Other techniques included the use of equipment for soil moisture measurement including G-Bug, Espan, pan evaporation, tensiometer, and Neutron Probe, or combinations of these.

Pesticides applied to potato crops vary greatly with geographic location. In Tasmania a typical fungicide regime consists of separate applications of the following: 8 applications of mancozeb, 2 applications of metalaxyl and 2 applications of azoxystrobin. Approximately 80% of fungicides are applied as ground sprays and 20% with aerial spraying. At emergence or 7-10 days post emergence of the crop, the typical weed control consists of one application of metribuzin applied to the field.

Harvest

The weather can influence harvest time of potato crops. In Tasmania, potato crops are harvested between late January through until August or September. Fresh market crops are grown all year round. Potato harvesting is mechanised and consists of a harvester digging potato from the field at approximately 8-10 t/hour. Approximately three people are required to operate the digger, with one tractor driver. Processing potato crops are then loaded onto trucks and transported to the processing factory or to the cool store to be processed at a later date. Tonnage for an average truck ranges between 7-30 t carrying capacity, with an average of 20 t per truck.

Although national average of potato yield is reported at 36 t/ha in 2007, industry representatives in Tasmania suggest that yields are much higher with commercial crops averaging 60 t/ha and seed crops (G2 and G3) averaging 50t/ha (Chris Russell and Les Murdoch, personal communication).

Storage

Storage operations include grading, seed cutting and cold storage of seed potato. In Tasmania, during April and July, potatoes are transported by bulk truck (10t-30t) to one of three cool-storage facilities located on the north-west coast. Forklifts are utilised to unload potatoes from bulk trucks into wooden half tonne bins. Bins are placed in dry store until grading is complete. Grading occurs between April and July. The grading process consists of a mechanised grader. Tubers pass over a roller system and excess soil and rocks are removed automatically. This is followed by grading personnel manually removing additional debris and malformed tubers. After the grading process is complete, samples of approximately 100 seed pieces are collected from each seed line and inspected by seed certification officers from the Tasmanian Institute of Agricultural Research. Where seed lines meet the criteria of seed certification, whole tubers are either transported to the cutting shed for seed cutting or placed as whole seed into cool store for approximately 5 months.

Traditionally, tubers were cut following cool storage, but in operations there has been a shift to the use of pre-cut seed (cut prior to storage). In Tasmania, seed was usually cut by centralised mechanised seed cutters (10t/hr), however some operations now use a mix of machinery (25%) and manual hand cutting (75%). Under this latter method of seed cutting, approximately 8t seed/hr seed can be processed. This may involve up to 24 staff per day to cut seed (includes machines and hand cutting operations). After cutting, the seed pieces are treated with fungicide and then placed in dry store to cure the cut surface of the seed piece for approximately 10-20 days. Following the curing process the cut seed is cool storaged for approximately 5 months. Seed is removed from cool store approximately 3 weeks prior to the planting of seed pieces the following season and maintained at ambient temperature for between 3-20 days until being bulk transported by truck to the field for planting (Andrew Langmaid, personal communication 2008). A typical large seed grading, cutting and cool storage facility in Tasmania handles approximately 12 000 tonnes of seed potato annually. About 75% of this tonnage is of suitable quality to retain as seed (Andrew Langmaid, personal communication 2008).

Based on data for 2005/2006, fungicide treatments applied to cut pieces of potato seed by potato growers in Tasmania and Victoria include firbark and mancozeb. The majority of growers did not apply fungicides treatments prior to planting. The fungicides thiabendazole and imazalil or a combination of both treatments was typically applied to cut seed to protect the seed piece. Other seed treatments used prior to storage of seed included cement (7%), Firbark (12%), Nubark (19%) and mancozeb (2.7%) or combinations of these chemical treatments, with cement and firbark (18%) the most commonly used combination. The vast majority of seed was stored at a cool store facility.

The National Standards requires potato lines in cool stores to be separated and clearly labelled to ensure the lines are not mixed. Storage bin hygiene is important to reduce the risk of disease transmission and recommendations are given by the National Standards to ensure a high level of control of seed quality. If used bins and bulk trucks are utilised for packing and transport, a cleanliness declaration certificate must be supplied (Anon. 2001).

2.3 The benchmark crops – Onions and Broccoli

A preliminary examination of the environmental footprint of the onion and broccoli industries in Australia was also undertaken in the present study. This was done to provide a comparison to the processing potato industry and to illustrate how the environmental footprint models can be used to compare and benchmark different horticultural industries.

An outline of the onion and broccoli industries is given below. This information was used to develop models of the environmental footprint of both industries.

Onions

Some 221,923 tonnes of onion were grown in Australia in 2006 from 4537 ha (ABS 2008). The main producers were South Australia (36.4%), Tasmania (31%) and Queensland (12.4%). Tasmania produces some 90,000 tonnes from 1500 ha (ABS 2008) and produces approximately 85% of Australia's onion exports. Most onions are exported to the U.K., continental Europe and Asia (DPIW 2008).

In Tasmania, onions are sown in either autumn or spring and harvested in January/February. The average yield of an onion crop in Tasmania varies from 55 t/ha (early planting) to 65 t/ha (main crop), with some 85-95% marketable as 1st or 2nd grade. Irrigation varies from 1 ML/ha for early to 3-4 ML/ha for a late planted onion crop.

Broccoli

The broccoli industry in Australia consists of some 6403 ha producing 48,398 tonnes in 2006 (ABS 2008). The major producers were Victoria, Queensland and Tasmania with 45.8, 21.1 and 11.9% of production, respectively (ABS 2008).

The case study was conducted for a processing company in Tasmania which contracts some 220 ha of broccoli annually within Tasmania. Approximately half of the crop is located on the north west coast and the remainder around Cressy. Crops are grown from transplants produced by a local nursery (Hills Transplants, Don, Tasmania). Seedlings are raised in a peat-based, seed-raising mix and treated weekly with fungicides and insecticides to control disease.

Preparation of fields for broccoli production along the north west coast of Tasmania includes cultivation of the soil approximately 1-2 weeks prior to planting with one pass of the rotary hoe. Field preparation in the Cressy region of Tasmania includes one pass of a plough and one pass of a tyne cultivator. Some 75% of fields are transplanted using a contractor, with the remainder of growers using their own two or four-row planters.

Lime is not normally applied as part of soil preparation for a broccoli crop. Fertiliser application at planting includes band placement of N:P:K (14:16:11) at 800 kg/ha. Top dressing of urea (46% N) occurs usually once prior to buttoning via a tractor and super spreader. Approximately 30% of broccoli growers apply sodium molybdate (1-3 sprays during the season.

Weed control consists of a pre-burn off with glyphosate and an application of oxyfluorfen applied close to the time of transplanting. Mechanical weed control is used, consisting of two inter-row passes at 4 weeks and 8 weeks after transplanting.

The main pests to affect broccoli production in Tasmania are aphids and caterpillars (from diamond black moth and cabbage white butterfly). Between 2-6 applications of various combinations of insecticides are applied after head formation. Approximately 50% of growers use older generation organophosphates or synthetic pyrethrins at least once during the season due to their low cost. Some of the insecticides used by the industry include spinosad, emamectin and alpha-cypermethrin.

The main diseases affecting broccoli in Tasmania are white blister (*Albugo candida*) and non-specific head rot. Two applications of either Amistar (azoxystrobin) or Ridomil Gold (metalaxyl) are used for disease control of white blister. No disease control is currently available for head rot.

Irrigation varies in different broccoli growing regions of Tasmania. All growers use centre pivot use in the Cressy area while around 40% of growers use travelling gun irrigator and 60% use centre pivots on the north-west coast. The growing season is 70-90 days from transplanting and it is common under Tasmanian conditions to apply irrigation water weekly (*ca.* 25 mm per pass). Around 2.5 ML/ha is commonly applied to crops.

Broccoli heads are harvested by hand into 170 kg bins. Approximately 20 bins can be transported by truck at a time, with up to 160 bins collected from one field per day. Harvest involves 2 tractors and drivers and a crew of approximately 8 people to cut broccoli. Alternatively, in large fields, 2 crews of 8, and three tractors (3 drivers) are used.

The average yield of processing broccoli in Tasmania is 14 t/ha. The main variety of broccoli grown in Tasmania is var. 'Shamrock', which has replaced var. 'Marathon'.

Comparing the processing potato, onion and broccoli industries

The onion and broccoli industries are quite different in nature and provide a contrast to the production cycle of the processing potato industry in Australia. As a consequence, they were considered to be suitable to illustrate how environmental footprint models could be employed to benchmark different horticultural industries. The nature of the environmental footprint model development and the findings of the models for the onion and broccoli industries are presented in the latter part of Section 4.

3. SIGNIFICANT ENVIRONMENTAL ISSUES FACING THE PROCESSING POTATO INDUSTRY

3.1 Introduction

Our review of the current environmental sustainability issues associated with the processing potato industry in Australia indicates concerns about:

- the use of fertilizers and pesticides,
- energy use and greenhouse gas emissions
- the management of key natural resources such as soils and water
- the conservation of biodiversity
- adaptation to climate change and variability.

These topics are considered in more detail below in the context of evaluating the environmental footprint of the processing potato industry. Since the implications of climate change and climate variability were covered earlier in Section 1, these topics are not discussed below.

3.2 Water use

Recent droughts highlight the importance of water availability in Australia. The potential for climate change to cause further water shortages is of major concern. It is very likely that with water shortages and the increasing cost of water, industries will be required to increase their water use efficiency in the future.

The major consumer of water in the Australian economy is the agricultural industry, with 12,191 gigalitres GL (65%) of total water consumed in 2004/2005. Water use in agriculture is estimated to have decreased since 2004/2005 by 30.1% to 8,521 GL in 2006/2007 (Table 3.1). This decrease has been attributed to a reduction of water use for irrigation of pastures, crops, rice and cotton (ABS 2008).

Table 3.1 Water consumption gigalitres (GL) for agricultural irrigation in Australia by State (2006-2007) (adapted from ABS 2008).

	Water Consumption (GL)							
	NSW+ ACT	**VIC**	**QLD**	**SA**	**WA**	**NT**	**TAS**	**Total**
Irrigation	2605	1649	1840	966	293	20	263	7636
% of total	91.6%	90.5%	88.3%	93.3%	71.2%	58.8%	91.3%	89.6%
Total agric. Water	2845	1823	2084	1035	412	34	288	8521

Water for irrigating crops and pastures accounted for 89.6% of the total 8,521 GL water use in agriculture, with 10.4% used for other agricultural including cleaning piggeries and dairies and watering stock (ABS 2008) (Table 3.2). In 2006/2007 pasture for grazing was the highest agricultural irrigation user in Australia, using 2,008 GL at an application rate of 3.5 ML/ha and equating to 26.3% of the national irrigation volume. Irrigated vegetable crops had an estimated gross value of $1761 M or 19.4% of the value of all sectors ($9076 M) in 2004/2005 (ABS 2006).

Table 3.2 Water consumption gigalitres (GL) by agriculture sector during 2006/2007 (adapted from ABS 2006).

	Dairy	**Vegetables**	**Sugar**	**Fruit**	**Grapes**	**Cotton**
GL	1163.5	413.9	977.6	648.4	638.6	867.6
ML/ha	4.4	4.0	4.9	4.6	3.6	6.5

Nationally the main source of water for Australian agriculture in 2006/2007 was supplied from private or Government irrigation schemes, supplying 38.4% (3,276 GL) of the total volume of water used in agriculture. Other main sources of Australian agricultural water included groundwater (32.2%) and surface water (26.5%) (ABS 2008). For agricultural purposes in 2006/2007 the major source of water by volume in Victoria (57.7%), New South Wales (37.7%) and Queensland (36.3%) was supplied by private and Government schemes. In the Northern Territory (64.1%) and South Australia (57.3%) groundwater was the major source of water for agriculture. The major water source by volume for agriculture in Tasmania (78.3%) and Western Australia (33.7%) was supplied by surface water (ABS 2008).

3.3 Agri-chemical use

The Australian agricultural landscape consists of a wide-range of soil types, although mostly infertile soils consisting of nitrogen and phosphorus deficiencies. To address these deficiencies application of nitrogenous and superphosphate fertilisers is common practice especially in cereal crops and pasture (ABS 2008). Although fruit and vegetable production accounted for only 1% of Australia's cropped area, however, it accounted for more than 15% of fertiliser use (ABS 2008).

Stringer (1998) noted that agricultural chemical use in Australia is low in comparison to other OECD countries. However, some 15 million hectares of land was treated with herbicide, 3 million hectares with insecticide and almost 1 million hectares with fungicides (ABS 1996). Estimates of the annual gain in net productivity from farm chemical usage in Australia ranged from A$2.5 billion to $5 billion.

Pesticide residue has been an issue and is of concern to the Australian agricultural industry. The rotation of potato production with pastures for sheep and beef grazing in Western Australia led to a major residue issue for the beef industry in the mid-1980's. At this time organochlorine (OC) insecticides were used in potato production in Australia. Residues of OC insecticides subsequently entered pastures which were grazed by beef cattle resulting in OC residues in Australian beef. A ban on all beef exports to US was avoided only after intensive cattle lot testing, which cost the beef industry some A$50 M (Hill et al. 1997).

The application of fertiliser during cultivation of potato crops grown on krasnozem soils in Australia results in a higher level of phosphorus remaining in the field, with less P removed during the harvesting process. Traditionally, Tasmania and Victoria have had high rates of P applied to vegetable crops grown on krasnozem soils. For example typical application rates for the potato variety Russet Burbank range between 150-300 kg P/ha (Sparrow 2002). Johnson and

Sparrow (2002) investigated reducing the use of fertiliser P in the potato industry on krasnozem soils to decrease soil additions of P and cadmium and reduce the cost of fertiliser P during cropping production. Trials were conducted in Tasmania over three consecutive potato growing seasons consisting of treatments with granular and liquid form starter P fertiliser and fertiliser in granular form placed with irrigation. The results did not suggest a beneficial effect from a reduction in P inputs on potato crops (Sparrow 2002).

3.4 Cadmium

The use of superphosphate fertiliser which contains contaminant residues of cadmium has been an issue of major concern to the Australian potato and vegetable industries. This led to the establishment of the National Cadmium Management Committee which oversaw a National Cadmium Minimisation Strategy (Warne et al. 2007). Cadmium is a naturally occurring heavy metal which can cause health problems including renal dysfunction in humans after long-term exposure. In Australia, the level of cadmium in soils (0.1 – 0.5 mg/kg) and in the Australian diet is low, and unlikely to contribute to health problems (Warne et al. 2007). However, continual application of phosphatic fertiliser and other sources such as trace element fertilisers, phosphogypsum and sewage sludge could lead to cadmium problems in the long term. Vegetable production is particularly at risk, as cadmium can be concentrated in particular plant parts including leaves and tubers.

Concentrations of cadmium in potato tubers increase with increasing chloride in irrigation water. The probability of cadmium in potato reaching the maximum permissible concentration (0.1 mg/kg) was found to be low when using irrigation water with a conductivity of less than 2.0 dS/m, but increased to 50% of Maximum Permitted Concentration (MPC) as the salinity of irrigation water increased past 3.0 dS/m (Warne et al. 2007). Salinity can also directly reduce potato production (Hickey and Hoogers 2006). Potato varietal selection is also important for cadmium uptake, with some potato varieties (e.g. Kennebec) having a high propensity for cadmium uptake and others (e.g. Russet Burbank) having a low uptake. Nationally phosphatic fertilisers have a maximum permitted concentration of 300 mg cadmium per kg P. However, the fertiliser industry has implemented a voluntary agreement to produce phosphatic fertiliser with a maximum of 100 mg cadmium per kg P for at risk industries such as horticulture (Warne et al. 2007). In a survey of fresh fruit and vegetables between 1997 and 2000, only 2/183 samples (1.1%) were above the MPC for cadmium (Warne et al. 2007).

3.5 Soil management

A large proportion of fruit and vegetable production in Australia occurs near rivers or close to coastlines where the likelihood of nutrient run-off and pesticides entering waterways may be increased. Nutrients added to agricultural systems in the form of fertiliser or manure have the potential to leach into waterways and contribute to eutrophication and undesirable environmental outcomes (e.g. algal blooms). The main sources from agriculture are through excessive use of fertiliser contributing to leaching of nitrate (NO_3) and phosphate (PO_4) into waterways and emissions of ammonia (NH_3) into the atmosphere. Due to the pollution of Sydney's waterways, potato growers in the highlands of New South Wales were forced to change traditional farming practices in the mid 1990's by catchment authorities and local government (Stringer 1998). A variety of management practices were put in place including the contouring of land, installation of silt traps and improved irrigation. These initiatives increased yield by 18%, which helped to compensate for the costs of remediation (HRDC 1997).

Stringer (1998) considered two broad types of environmental problems linked to Australia's fruit and vegetable sectors; i) pollution and contamination of soil, water, air and food resulting from the use of farm chemicals; and ii) degradation of natural resources, especially the deterioration in the available quantity and quality of soil and water. Intensive vegetable production includes practices which are conducive to erosion and include:

- large areas of bare earth at times become exposed to the rain
- intensive cultivation and cropping reduces organic matter and degrades soil structure, increasing the potential for erosion.
- soil compaction from cultivation can create tillage pans which reduce water infiltration rate and promote increased runoff.

- cultivation up and down slopes which is necessary for the use of harvest and cultivation equipment, which promotes runoff and increased soil erosion.

Elliott and Cole-Clark (1993) reported estimates of erosion from potato lands on Kraznosems at Dorrigo New South Wales with an average annual rainfall of 2000 mm. On a site with slope gradients ranging from 5-21%, total erosion following three spring crops of potato in rotation with kikuyu based pasture averaged 297 t/ha, with point losses of between 0 and 1190 t/ha. This was equivalent to 98 t/ha per crop allowing for erosion associated with the pasture phase. In a second field with slope gradients between 5-12%, in which there had been two successive potato crops, erosion rates of 57 t/ha per crop were noted in comparison to permanent pasture (0.09 t/ha/year). The loss of 100 t/ha topsoil due to erosion was calculated to involve the loss of 5 t organic carbon, 470 kg of total N, 140 kg of total P, 50 kg of Ca, 12 kg of Mg, and 39 kg of K (Elliot and Cole-Clark 1993). To replace the carbon would require the incorporation of approximately 20 green manure crops, while to replace nutrients would require some $3200 per hectare of fertiliser (based on 1992 figures).

Soil compaction is often a problem in potato production due to the need to cultivate the soil at times when soil moisture is high. Stalham et al. (2007) examined the effect of soil compaction in potato crops in the U.K. They reported maximum rates of root growth of 20 mm/day in intensively cultivated surface horizons, which halved when soil resistance approached $\Omega = 1$, and reduced to <2 mm/day when $\Omega = 3$. In a survey of 602 commercial fields, some 2/3rds of fields had $\Omega \geq 3$ MPa at *ca*. 0.6 m, within the desirable rootzone depth of 1 m (Stalham and Allen 2001). This suggested that the majority of potato crops in the UK had soil conditions which would markedly restrict both growth rate and depth of roots.

Stalham et al. (2007) noted that many growers responded to problems of compaction by top-dressing nitrogen and increasing the amount of irrigation applied. This strategy is wasteful of resource and may not fully compensate. For example, total yield of Maris Piper in an unirrigated situation was 40.5 and 33.2 t/ha for uncompacted and compacted respectively, while in an irrigated situation was 53.6 and 32.6 t/ha, respectively (Stalham et al. 2007). Stalham et al. (2007)

noted that the use of powered cultivators to separate stones and clods from seedbeds in the UK had increased the risk of soil compaction in recent years.

3.6 Greenhouse gases emissions

Carbon emissions from agricultural systems occur through, i) fossil fuel use resulting from food production, ii) embodied energy of inputs that require energy-intensive manufacture and, iii) loss of organic soil matter resulting from soil cultivation (Ball and Pretty 2002). Changes to land use and the direct effects of land use have resulted in net emissions of 1.7 Gt C/yr and 1.6 Gt/c/yr in the 1980s and 1990s, respectively (IPCC 2000 cited in Ball and Pretty 2002).

Emissions of GHG from agriculture are inherently difficult to estimate in comparison to other sectors, due to the large geographic area involved, fluctuations over time and the influence of management and environmental factors on emissions (Anon 2008a). Research is currently underway in Australia to develop emission calculations based at the enterprise, property and regional scale (Anon 2008a). Recently, Lincoln University in New Zealand has produced a web based 'Agriculture and Horticulture Carbon Calculator' to give farmers an estimate of annual greenhouse gas emissions produced by a horticultural farm (no stock) or an agricultural/mixed farm (with stock) www.lincoln.ac.nz/aeru (accessed 23 June 2008). A calculator for assessing domestic emissions in Australia is also available (www.carbonneutral.org.au). The total annual emissions of CO_2 equivalents in the agriculture, fish and forestry sector for each state are given in Table 4.3. In 2005/2006, Queensland (69.3 Mt CO_2-e) was estimated to have the highest annual emission of CO_2 equivalents for the agriculture, fish and forestry sector, while South Australia (1.8 Mt CO_2-e) had the lowest emissions.

Lisson (2008) reviewed the following four models and calculators that could be adapted to estimate greenhouse gas emissions: FullCAM (Australian Department of Environment and Heritage), Grains Greenhouse Calculator (Department of Primary Industry Vicotoria), APSIM (Agricultural Production System Research Unit) and CarboNZero (New Zealand Crown Research Institute). Individually, these tools are not currently suitable for immediate application for the Australian vegetable industry due to limitations in operation and design. However, with further development they could be combined to create a suitable a calculator for use in vegetable greenhouse accounting as they possess the necessary key functions and attributes (Lisson 2008).

Table. 3.3 Total annual emissions of CO_2 equivalents in the agriculture, fish and forestry sector by State (2006) (Anon 2008a).

	NSW	VIC	QLD	WA	SA	TAS	NT
Mt CO_2-e	29.1	12.0	69.3	11.6	1.8	2.6	10.1

Nitrous oxide

Anthropogenic activities such as combustion of fossil fuels and application of fertiliser have resulted in emissions of nitric oxide (NO) and nitrous oxide (N_2O) (Stehfest and Bouwman 2006). Nitrous oxide is considered to be the main GHG released from agricultural production (Stehfest and Bouwman 2006). Two main sources of N_2O emissions in agriculture are:

- Denitrification: $NO_3^- \rightarrow N_2O \rightarrow N_2O + N_2$
- Nitrification: $NH_4^+ \rightarrow NO_2^- \rightarrow N_2O + NO_3^-$

N_2O emissions resulting from Australian agriculture and suggested mitigation options were reviewed by Dalal et al. (2003). They estimated that, since 1750, N_2O concentrations have increased by 16%. Agricultural lands in Australia emit 80% of the national N_2O emissions with contributions from soil disturbance (38%), N fertilisers (32%) and animal waste (30%). Thomas *et al*. (2004) demonstrated that N_2O emissions were greater from tractor compacted areas in a potato field compared with non-compacted areas in the field. Based on a fertiliser rate of 225 kg N/ha, calculations of net N_2O surface flux emissions were estimated over four months of a potato crop to be 0.43, 1.05 and 2.88 kg N/ha from uncompacted furrow, ridge and compacted furrow, respectively. Furrows represented some 25%, and ridges some 50% of the soil area. Emissions were higher when water filled porosity of the soil was high (>55%) following rain or irrigation.

Similar mean emission values for potato soils have been found by other workers (e.g. 3-4.7 kg N/ha in Scotland, Dobbie et al. 1999; and 2.4 – 4.1 kg N/ha in Germany, Flessa et al. 2002).

Carbon sequestration

It is important to recognise agriculture can, in addition to emitting GHG, accumulate carbon and can offset carbon emissions. Some ways carbon can accumulate in agriculture include within the soil through organic matter additions to the soil, by the use of permanent sinks in above- and below-ground biomass, and through the use of energy sources that avoid fossil fuels and subsequent emissions of carbon (Ball and Pretty 2002).

Carbon levels in Australian in rain-fed cropping soils are generally low, often with organic carbon levels less than 1%. Levels are less (0.5%) in sandy loam soils such as in the Mallee or in Western Australia (Valzano et al. 2005). The level of carbon in the soil can be seriously altered by drought and changes in agricultural practices such as different tillage systems, fertiliser practices and crop rotations. Over the past 20 years the amount of tillage used has decreased in some cropping systems (e.g. grain) with the adoption of crop stubble retention and a no-till approach. As a result to changes in cultural practices fuel consumption has resulted in reduced GHG emissions from soils. In addition, adoption of the no tillage approach has resulted in increased carbon levels in the soil by reducing oxidation of plant matter and minimal disturbance (Valzano et al. 2005).

Tillage practices have been shown to impact on soil carbon levels. As part of the National Carbon Accounting System (NCAS) a new modeling approach was implemented by the Australian Greenhouse Office (AGO) (Department of the Environment and Heritage) to estimate soil carbon fluxes occurring from land use changes (Valzano et al. 2005). The results of this review were based on total soil carbon with no distinction made between different soil carbon forms. The project involved evaluation of soil carbon and the impact of management practices of land use, climate, location, and soil type. This review highlighted a 10-30 t/ha reduction in soil carbon density in soil to a depth of 30cm in well established pasture or uncleared land that had been reintroduced to a cropping phase. Soil carbon levels can be directly influenced by soil type.

Higher carbon levels were reported in soils that were well structured such as ferrosols compared to soils that were poorly structured (e.g. sodosols). On poor quality soils such as sodosols, carbon levels may be low regardless of the tillage intensity used (Valzano et al. 2005).

4. QUANTIFYING THE ENVIRONMENTAL FOOTPRINT OF THE PROCESSING POTATO INDUSTRY IN AUSTRALIA.

4.1 Introduction

A number of approaches have been used to consider the environmental performance, environmental footprint and carbon footprint of different sectors and industries within western economies. These approaches often are based on a form of 'life cycle' assessment (LCA) of the industry of interest.

LCA is used to assess the environmental impact of a product or overall industry and the assessment may include a quantification of emissions from inputs and outputs of pre-farm, on-farm and post-farm sources. The advantage of using LCA to assess the potential environmental impact of crop production is that it relies on inputs and outputs from the entire production systems rather than a focus on an individual emission source (eg. N_2O emissions from on-farm application of N). LCA of greenhouse gas emissions in cropping systems has been restricted mainly to Europe with limited studies conducted in Australia (Biswas et al. 2008).

Examples of LCA studies conducted in the Australian agricultural industry include for wheat production (Biswas et al. 2008) and irrigated maize production (Grant and Beer 2008). Biswas et al. (2008) assessed the greenhouse gas life cycle in Western Australia associated with the production of 1 tonne of wheat (ceasing with the transport of wheat to port). Analysis of emission included stages from pre-farm, on-farm and post-farm. Approximately 35% of GHG emission was attributed to fertiliser production during the pre-farm stage. CO_2 emissions from on-farm activities contributed to 27% of GHG, followed by 12% emissions from input and wheat transport (Biswas et al. 2008). In another study, Grant and Beer (2008) used LCA to investigate the GHG emissions associated with the supply chain of irrigated maize (to the point of the chain when corn chips are manufactured). Pre-, on- and post-farm emission were investigated and compared. The largest GHG emission source was on-farm N_2O resulting from the application of fertiliser. These emissions equated to 0.126 kg CO_2-e per 400 g packet of corn chips. Electricity use was the most significant source of GHG emissions during the manufacture of corn chips (0.086 kg CO_2-e per 400 g packet of corn chips) (Grant and Beer 2008).

Lillywhite et al. (2007) assessed the environmental footprint, economic and social impact of the horticultural production in the UK, enabling comparisons to be made between different horticultural sectors. LCA conducted by Lillywhite et al. (2007) on potato crops in UK assumed crops were main crops, yield of 45 t/ha, application of 200 kg/ha of nitrogen and a plough based tillage system. Lillywhite et al. (2007) determined the environmental footprint of the potato in UK is 27.1 (environmental footprint, ha). The footprints of other crops assessed in this study (cauliflower (20.3), onion (20.3), carrot (19.3) and winter wheat (11.5)) were all lower. Pesticide and water were considered the largest influences on the environmental footprint. In addition Lillywhite et al. (2007) reported potato to have the highest acidification, eutrophication and global warming potential values compared to other horticultural field crops assessed. These higher values were attributed to the high use of nitrogen fertiliser (Lillywhite et al. 2007).

Lillywhite et al. (2007) showed a slight decrease in the environmental footprint denoted between arable crops (e.g. potato) and horticulture crops such as onion and carrots and attributed this to high labour and nitrogen requirements. Although arable crops were determine by Lillywhite et al. (2007) to have the lowest environmental footprint for commodities studied, arable crops also had a much greater impact due to covering the greatest area of land.

In addition to the study conducted by Lillywhite et al. (2007), other LCA conducted on potato especially in the UK include Williams et al. (2006), Mattsson and Wallen (2003) and although not comparable to other studies due to the underlying methodology, the Danish LCA Food data base includes potatoes. Within the fruit and vegetable industry in the UK food market the single most important product is potato (Flynn et al. 2004 cited in Foster et al. 2006). Approximately 6 millions tonnes of potato were produced in the UK in 2004 (British Potato Council), with processed potatoes equating to approximately 2 million tonnes (Flynn et al. 2004 cited in Foster et al. 2006). Apart from our study no other LCA for processed potato industry are currently available.

In the UK production of 1kg of potatoes and associated environmental impacts were summarised by Williams et al. (2006). Results from Williams et al. (2006) are comparable with an earlier study conducted by Pimentel and Pimentel (1996) (cited in Foster et al. 2006) and included an estimate of 1.4 MJ/kg energy input in production in the UK, with Williams et al. (2006) reporting energy used to be 1.3 MJ/kg. Results from work by Mattsson and Wallen (2003) (cited in Foster et al. 2006) assessing the LCA and environmental impact of producing organic potatoes, suggested less energy inputs were required (0.6 MJ/kg peeled potato, equivalent to 1.7kg of field potato) in organic production in comparison to conventional (non-organic) production. However, energy inputs during organic potato production in the UK assessed by Williams et al. (2006) were found to be similar to that of conventional production (Table 4.1). Williams et al. (2006) suggested the additional machinery operations required in organic potato production replaces the fertiliser energy requirements in non-organic potato production resulting in similar energy inputs for each cultivation system. This also reflects the higher land area required for organic potato production compared to non-organic with 0.058 ha/t and 0.022 ha/t, respectively (Table 4.1).

4.2 General approach to environmental footprinting adopted for this study

'*It has long been argued that the complexity and multi-faceted nature of agricultural sustainability cannot be resolved to a single metric*' (Pretty et al. 2007). Due to this recognised complexity we chose several commonly-used measures of the environmental footprint of agricultural systems to assess the congruence of the modelled outputs. Specifically, we have employed two different scenarios (Scenario 1 and Scenario 2) to quantify and model the environmental footprint of the processing potato industry, based on different ways to assess the inputs and outputs to production. This has allowed us to identify consistent trends associated with the actual production process, as opposed to those which arise more as an artefact of the method of analysis.

Williams et al. (2006) found approximately 50% of the total energy input was attributed to cooling the potatoes in storage. Another important practice highlighted by Williams et al. (2006) was irrigation.

Table 4.1 Environmental impact (per tonne of tubers) of producing potatoes non-organically and organically (adapted from Williams et al. 2006).

Impacts & resources used	**Non-organic**	**Organic**
Primary Energy used, MJ	1,260	1,280
GWP_{100}, kg 100 year CO_2 equiv.	215	199
EP, kg PO_4^{3-} equiv.	1.1	1.2
AP, kg SO_2 equiv.	1.9	0.8
Pesticides used, dose ha	0.5	0.1
ARU, kg antimony equiv.	0.9	1.1
Land use grade 3a ha	**0.022**	**0.058**
N losses		
NO_3^-- N kg	1.39	2.04
NH_3^-- N kg	0.3	0.27
N_2O- N kg	0.7	0.06
N_2- N kg	0.98	0.88
Irrigated water, m^3	17.4	3.9
Primary Energy Usage Proportions		
Field diesel	28%	35%
Machinery manufacture	8%	13%
Crop storage and drying or cooling	36%	40%
Pesticide manufacture	3.9%	0.8%
Fertiliser manufacture	24%	11%
Total	**28%**	**35%**
Global Warming Potential*		
CO_2	45%	49%
CH_4	2%	1%
N_2O (direct)	48%	42%
N_2O (via nitrate)	4%	7%

*The ability of different greenhouse gases to trap heat in the atmosphere is assessed as Global Warming Potential.

Our study involved the collection of information for seed potato grading and storage (Cherry Hill, Tasmania), and potato production from agronomy staff of Simplot Australia Pty. Ltd. (Tasmania), McCain Foods Australia Pty. Ltd. (Tasmania), Allan Smith (Snack Brands Australia, Queensland) and Matt Bennett (Mallee, South Australia). Information was also sourced for onion production (Tim Groom pers. comm.) and processing broccoli production (Petra Novak, Simplot Australia Pty. Ltd.) in Tasmania.

Four potato case studies were undertaken: Tas 1 (processing, var. Russet Burbank), Tas 2 (processing var. Mac 1), Tas 3 (processing var Russet Burbank), Mallee (processing var. Russet Burbank), Lockyer Valley (processing, vars. Kennebec and Shepody). To demonstrate the ability of our methods to allow for benchmarking of the processing potato industry to other agricultural/horticultural industries, we have included a preliminary environmental footprinting evaluation of the farm to factory gate processes involved in the onion and broccoli agricultural production systems in Tasmania.

Two different scenarios for evaluating the environmental footprint of the processing potato industry in Australia were examined (discussed below). Note that, at present, the quantitative modelling of the environmental footprint of the industry only considers the ‘farm to factory gate’ aspect of the overall production and distribution system, although some consideration was given in the analysis to the movement of inputs to the farm gate.

Energy use

Energy use in a production system can be a useful indicator of environmental impact. Energy is presented in units of gigajoules (GJ) or megajoules (MJ) per unit production or per hectare. Energy includes direct energy comprising fuel and electricity inputs for heating, lighting, power, irrigation, ventilation etc. and indirect energy which includes embedded energy inputs for the manufacture of fertilisers, pesticides, machinery etc. (Plassmann and Jones 2007). Bailey et al. (2003) considered that energy analysis may be the only method which allows comparison between different agricultural systems.

In this study we used the methods of Lillywhite et al. (2007) to calculate an energy use ratio, i.e metabolisable energy (ME) associated with the marketable crop, divided by the energy inputs required to produce the crop (Metcalf and Cormack 2000). A high ratio is desirable and a ratio above one indicates a theoretical net energy gain (Lillywhite et al. 2007). Secondly the ‘energy productivity’ (MJ/tonne marketable crop) was calculated as energy (MJ/ha) required to grow the crop divided by the amount of marketable crop (t/ha).

Global warming potential

Greenhouse gases considered important in agricultural systems include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The ability of different greenhouse gases to trap heat in the atmosphere is assessed as Global Warming Potential (GWP), which is based on the radiative efficiency (ability to absorb heat) and the decay rate of each gas within the atmosphere relative to CO_2 over different time frames. Thus over 100 years the GWP for CO_2, CH_4 and N_2O is 1, 23 and 310, respectively (IPCC 1996), indicating that the latter two have greater capacity for global warming than the former.

Although having the lowest GWP, CO_2 is the major greenhouse gas considered to cause some 70% of global warming, due principally to burning of fossil fuels and land use change (www.carbonneutral.org.au). Methane accounts for some 23% of global warming with significant man-made sources from fugitive emissions from fossil fuel extraction, anaerobic decomposition of organic matter in landfill and agriculture and smoke from burning. Nitrous oxides account for 7% of global warming with emissions from nitrogen fertilisers and application to agricultural land under damp, warm conditions.

Eutrophication and acidification potential

Nutrients added to agricultural systems in the form of fertiliser or manure have the potential to leach into waterways and contribute to eutrophication and undesirable environmental outcomes (e.g. algal blooms). The main sources from agriculture are leaching of nitrate (NO_3) and phosphate (PO_4) into waterways and emissions of ammonia (NH_3) into the atmosphere. Eutrophication Potential (EP) is a measure of the potential of particular nutrients to cause eutrophication relative to phosphate (Table 4.2)

Acidification results from acids, and compounds which can be transformed into acids, being emitted into the atmosphere and subsequently deposited in surface soils and water. The main agricultural sources are NH_3 which when deposited in the atmosphere is oxidized to nitric acid. Another source is sulphur dioxide (SO_2) from combustion of fossil fuels.

Table 4.2 Relative eutrophication potential of nutrients.

Nutrient	Eutrophication Potential (PO_4-equivalents)
Phosphate (PO_4)	1.00
Nitrate (NO_3)	0.42
Ammonia (NH_3)	0.33
Oxides of nitrogen (NO_x)	0.13

Increased acidity in the environment is undesirable due to effects of acid rain on forests, death of fish, and increased corrosion of man-made structures. Acidification potential (AP) is a measure of the ability of particular chemicals to contribute to acidification relative to SO_2 (Table 4.3)

Table 4.3 Relative acidification potential of chemicals released during agricultural production.

	Acidification potential (SO_2-equivalents)
Sulphur dioxide (SO_2)	1.00
Oxides of nitrogen (NO_x)	0.70
Ammonia (NH_3)	1.88

EP and AP are used in combination with knowledge of inputs into farming systems which may contribute to eutrophication and acidification and with estimates of the potential losses from the system to calculate the contribution of the system to eutrophication and acidification and are reported as kg/ha

In our study, the methods of Lillywhite et al. (2007) were used for estimating losses of SO_2, NO_x, NH_3, NO_3 and PO_4, which were used in the calculation of eutrophication and acidification potential (Table 4.4). In addition, eutrophication and acidification potential was re-calculated using Australian estimates of the emission of SO_2 and NO_x from the use of vehicles (Sinclair et al. 2003, National Pollutant Inventory 2008).

Pesticide use

The Environmental Impact Quotient (EIQ) method (Kovach et al. 1992) was used to assess the environmental impact of pesticide applications. Criteria used to assess each pesticide include: dermal toxicity, chronic toxicity (reproductive, teratogenic, mutagenic and oncogenic), toxicity to fish, birds, bees and beneficial arthropods, persistence in soil and on leaves, and potential for leaching or runoff. A single value is obtained from assessment of the risk of the pesticide to (i) farm workers (e.g. applicator and picker), (ii) consumers (health and leaching) and (iii) environment (fish, birds, bees and beneficials). Each of (i), (ii) and (iii) is given equal weighting within the final analysis, but individual factors within each are weighted on a one to five scale. For example, chronic toxicity is rated as 1, 3 or 5 depending upon whether the pesticide has little, potential or definite toxicity.

The formula for calculating EIQ is:

{C[(DT*5)+(DT*P)]+	Farmworker
[(C*((S+P)/2)*SY)+(L)]+	Consumer
[(F*R)+(D*((S+P)/2)*3)+(Z*P*3)+(B*P*5)]}/3	Environment

DT=dermal toxicity, C=chronic toxicity, SY=systemicity, F=fish toxicity, L=leaching potential, R=surface loss potential, D=bird toxicity, S=soil half life, Z=bee toxicity, B= beneficial arthropod toxicity, P=plant surface half life.

Once EIQ values have been calculated for each pesticide, a field use rating can be calculated based on the dose, amount of active ingredient in the formulation and application frequency.

EIQ Field Use Rating = EIQ * % active ingredient * rate/ha.

Use of the EIQ method allows a comparison between pesticides which might allow producers to choose pesticides and pesticide programs with lower impact. It also allows an industry to monitor the impact of changes in pesticide use over time.

4.3 Methods employed for Scenario 1

Scenario 1 was based on the methods of Lillywhite et al. (2007) who recently provided a comprehensive analysis of the environmental footprint of a number of horticultural industries within the U.K., including potato. Various inputs (e.g. fertiliser and pesticides) were converted into units of energy (MJ) based on data provided by Lillywhite et al. (2007), or where possible, from local sources. The methods used by Lillywhite et al. (2007) to calculate GHG emissions were based on IPCC (1996) and along with methods to calculate eutrophication and acidification potential are outlined in Table 4.4. In our study, we used a different method based on the Australian modification of the IPCC (1996) approach (NGGIC 2007). Details of the method of calculation are given in Table 4.5. In addition, pollutants from the use of vehicles were calculated using data from various sources (see Table 4.5). The method employed by Lillywhite et al. (2007) was used to determine acidification and eutrophication potential (Table 4.4). However acidification and eutrophication were also re-calculated on the basis of Australian estimates of SO_2 and NO_x emissions from vehicles (Table 4.5).

Crop residues

Transformation of organic N from crop residues and soil organic matter into inorganic forms is an important process which determines the pool of available N for the subsequent crop, or for leaching in the absence of crops and potential losses of N_2O. The IPCC (2006) reported a method of estimating the amount of residue and N-content associated with some crops, including potato. Alva et al. (2002) demonstrated that in Russet Burbank, final tuber, leaf and stem dry weight as a percentage of total plant dry weight varied from 76-85%, 9-13% and 6-11% respectively. Just prior to senescence of vines, total N in plants (excluding roots) was 350 kg N/ha, and total N in tubers, leaves and stems represented 68.6%, 19.4% and 12.0%, respectively. For the purposes of our study in potato it was assumed that the dry matter fraction of residue was 0.22, and of harvested product was 0.78.

The IPCC (2006) did not provide information on calculating crop residue associated with onion production. Sullivan et al. (1999) noted that the average N uptake by an onion crop (tops and bulbs) was the equivalent 1.75 kg N/tonne bulbs. Furthermore, the range of total biomass for all onion types was the equivalent of 10.09-13.45 t/ha (dry weight), with less than 2.24 t/ha (16.7-22.2%) in tops (Sullivan et al. 1999). For the purposes of our study the proportion of dry matter biomass in onion tops was considered to be 20%. This agreed with other studies quoted by Sullivan et al. (1999) in which the total N uptake by onion crops and the amount in tops was between 145.6-179.2 kg/ha and 11.2-33.6 kg/ha respectively (Eastern Washington) and 89.6-100.8 kg/ha and 16.8-22.4 kg/ha respectively (Malheur County, Oregon). This indicated on average some 13.8 and 20.6 kg/ha N was present in onion tops in these two studies. To estimate the N-content of crop residue in our study, the method of IPCC (2006) was used (Table 4.4).

Table 4.4 Methods used by Lillywhite et al. (2007) to calculate greenhouse gas emissions, eutrophication and acidification potential.

Component:	Method of calculation
Amount of crop residue	Based on local harvest index data
Nitrate leachate	Set value of 15% of nitrogen input
Nitrous oxide from nitrate leachate	0.0075 kg, per kg NO_3-N
Nitrous oxide from fertiliser-N	0.01 kg, per kg N
Nitrous oxide from residue N	0.01 kg, per kg residue N
Nitrous oxide from atmospheric deposition	Set value (0.27 kg/ha)
Nitrogen oxide from fertiliser	0.003 per kg N
Nitrogen oxide from fuel	0.0549 kg/L
Ammonia (NH_3) loss	0.01 per kg N
Sulphur dioxide from fuel	0.0028 kg/L
Phosphate (PO_4) leachate	0.065 per kg P
Eutrophication potential (PO_4-equivalents)	Sum of: (NH_3 loss * 0.33) + (NO_3 leachate * 0.42) + (PO_4 leachate * 1) + (NO from fuel and fertiliser * 0.13)
Acidification potential (SO_2-equivalents)	Sum of: (NH_3 loss * 1.88) + (NO from fuel and fertiliser * 0.7) + (SO_2 from fuel * 1)

The IPCC (2006) did not provide a method of calculating the amount of crop residue in broccoli. For our study, a harvest index of 0.23 (Vagen et al. 2003) was assumed, with 11% dry matter (Tan et al. 1999) and an assumption of 80% and 20% of biomass above and below ground, respectively. To estimate N-content in broccoli residue in our study, the method of IPCC (2006) was used (Table 4.4).

Transport

In contrast to Lillywhite et al. (2007), our study made allowance for the transport of inputs to the farm (e.g. fertilizer, contract machinery) and for the cartage of crop to the processing factory.

Table 4.5 Methods used to calculate greenhouse gas emissions, acidification potential and eutrophication potential in this study (Scenario 1), based on NGGIC (2007) unless otherwise stated.

Greenhouse gas emissions:	
N_2O emissions from N fertiliser	Amount of N fertilizer * emission factor (0.021) * 44/28[a]
CO_2 emissions from urea	Amount of urea fertilizer applied * emission factor (0.20) * 44/12[b]
CO_2 emissions from lime	Amount of lime applied * emission factor (0.12) * 44/12[b]
Amount of N remaining in crop residue	Amount of N in below ground residue = Yield * dry matter fraction of yield that is residue (0.22 for potato) * proportion that is below ground residue (0.2) * N content of below ground residue (0.014) Amount of N in above ground residue = Yield * dry matter fraction of yield that is residue (0.22 for potato) * proportion that is below ground residue (0.8) * N content of below ground residue (0.019)
N_2O emissions from crop residues	Amount of N in crop residue * emission factor (0.0125) * 44/28[a]
Amount of N fertilizer volatilized into the atmosphere as NH_3-N and NO_x-N	Amount of N fertilizer * emission factor (0.1)
N_2O emissions produced from atmospheric deposition	Amount of N fertilizer volatilized into the atmosphere as NH_3-N and NO_x-N * 0.01 * 44/28[a]
Amount of N fertilizer lost by leaching and run-off	Amount of N fertilizer * proportion capable of leaching or run-off [c]* default value of proportion of N lost by leaching and run-off (0.3)
N_2O emissions from leaching and run-off	Amount of N fertilizer lost by leaching and run-off * emission factor (0.0125) * 44/28[a]
Diesel use (MJ)[d]	38.6 MJ/L with CO_2-e emissions of 69.8 g/MJ
Petrol use (MJ)[d]	34.2 MJ/L with CO_2-e emissions of 67.0 g/MJ petrol
Avgas use (MJ)[d]	33.1 MJ/L with CO_2-e emissions of 67.1 g/MJ
LPG use (MJ)[d]	25.5 MJ/L with CO_2-e emissions of 57.0 g/MJ for light duty vehicle e.g. forklift.
Electricity use (MJ)[d]	3.6 MJ/kWh with scope 2 emissions (g CO_2-e/MJ) for each state of 249 (NSW/ACT), 340 (VIC), 252 (QLD), 233 (SA), 242 (WA), 35 (TAS) and 190 (NT).
Other pollutants:	
Vehicle emissions (Kg pollutant/L fuel)	
Carbon monoxide	3.22E-02 (diesel tractor), 1.84E-02 (diesel truck), 4.75E-01 (petrol car)

Formaldehyde	1.23E-03 (diesel tractor), 8.13E-04 (diesel truck), 5.23E-04 (petrol car)
Nitrogen oxides	5.24E-02 (diesel tractor), 4.41E-02 (diesel truck), 1.15E-02 (petrol car)
Particulate matter (PM_{10}) (particles less than 10 µm in aerodynamic diameter)	5.57E-03 (diesel tractor), 3.61E-03 (diesel truck), 7.26E-04 (petrol car)
Sulphur dioxide (kg/L)	3.73E-03 (diesel tractor/diesel truck), 6.33E-04 (petrol car)
Total VOC's (volatile organic compounds)	7.74E-03 (diesel tractor), 4.04E-03 (diesel truck), 1.56E-02 (petrol car)
LPG forklift emissions (kg pollutant/L)	
Carbon monoxide	0.016 kg/L (0.030 kg/kg)
Nitrogen oxides	0.025 kg/L (0.0463 kg/kg)
Total VOC's	0.0021 kg/L (0.0039 kg/kg)
Diesel stationary engine (kg pollutant/kWh)	Carbon monoxide (3.30E-03), nitrogen oxides (2.29E-02), PM10 (4.30E-04), sulphur dioxide (2.45E-05), total VOC's (3.80E-04)
Eutrophication potential (PO_4-e)	
Phosphate leachate	0.08 per kg P (280 kg/ha P) (Lillywhite et al. 2007)
Nitrate leachate	Assumed to be same as 'Amount of N fertilizer lost by leaching and run-off' calculated above. NO_3^- * 0.42 = eutrophication potential in PO_4-equivalents.
Nitrogen oxides from fuel combustion	Calculated as above. NOx * 0.13 = eutrophication potential in PO_4-equivalents.
Ammonia and NOx	Calculated as per amount of N fertilizer volatilized into the atmosphere as NH_3-N and NO_x-N (above). For the purposes of this study it was assumed that all volatilization was of NH_3. Amount of NH_3 volatilized * 0.33 = eutrophication potential in PO_4-equivalents.
Acidification potential (SO_2-e):	
Sulphur dioxide from fuel	Calculated as above.
Ammonia and NOx	Calculated as per amount of N fertilizer volatilized into the atmosphere as NH_3-N and NO_x-N (above). For the purposes of this study it was assumed that all volatilization was of NH_3. Amount of NH_3 volatilized * 1.88 = acidification potential in SO_2-equivalents.
Nitrogen oxides from fuel combustion.	Calculated as above. NOx * 0.7 = acidification potential in SO_2-equivalents.

[a] factor to convert the elemental mass of N_2O to molecular mass
[b] factor to convert the elemental mass of CO_2 to molecular mass
[d] Department of Climate Change (2008)
[e] Fraction of N available for leaching and run-off for horticultural vegetable crops is 0.599, 0.857, 0.293, 0.667, 0.996, 0.702 and 0.911 for NSW, NT, QLD, SA, TAS, VIC and WA respectively (NGGIC 2007)
[f] Sinclair, Knight Merz (2003)
[g] National Pollutant Inventory (2008)

For transport of machinery to the farm associated with a tractor, a round trip of 100 km and an on-road diesel consumption of 60.8 L/100 km (http://www.dlg-test.de/pbdocs/5435F_e.pdf) was assumed. To allocate diesel usage on a per hectare basis it was assumed that the average potato field was 10 ha in size.

For each crop type studied, an allowance was made for petrol associated with car usage of farmer and agronomist associated with crop. For each crop it was assumed there were 10 trips of 50 km each and fuel consumption of 9.5 L/100 km. To allocate petrol usage on a per hectare basis it was assumed that the average potato field was 10 ha in size.

Irrigation

Irrigation in the Australian vegetable industry is predominately by centre pivot, linear move or big gun travelling irrigator. Information on electricity usage associated with irrigation was sourced from a local irrigation company (Ron Lambert, Seattle Services Pty. Ltd., Latrobe, Tasmania). Most current centre pivot systems in Tasmania operate with end of system pressures of 15-35 psi. A centre pivot with 15 psi end of system pressure operating 10 psi pressure regulated sprinklers and base of inlet pressure of 21.5 m (30.5 psi) requires 87 kWh/ML water. There is a further requirement of 12 kWh/ML water to power the centre pivot, giving a total of 99 kWh/ML water. This figure was used in our study for centre pivot systems.

Most travelling irrigators operate with sprinkler nozzles operating at 60-90 psi. A typical travelling irrigator is equipped with $3^{1/2}$ inch x 200 m layflat hose operating 16 L/second nozzle @ 70-75 psi. In this situation water supply to hydrant to layflat hose inlet pressure of 60 m (85 psi) would require a total of 242 kWh/ML water. This figure was used in our study for travelling irrigator systems. Note the above estimations for centre pivot and travelling irrigator do not take into account supply pipeline friction losses or water source to the irrigator head requirement.

The estimations above are similar to those of Maskey et al. (2007) who compared two, 400 m long (50 ha) centre pivot irrigation systems in Victoria, Australia; one with a centre pressure of 29.5 m (42 psi) and the other with a centre pressure of 21 m (30 psi) operating 7 m (10 psi) regulated sprinklers (Table 4.5). Where diesel pumps were employed for irrigation, a figure of 27 L diesel/ML water was used in our study (Table 4.6).

Table 4.6 Electricity (kWh) or diesel (L) required to pump a megalitre of water with two different centre pivot systems (Maskey et al. 2007).

Total head (m)	Electricity consumed[1] (kWh/ML water)	Diesel consumed (L diesel/ML water)
Centre pressure of 29.5 m (42 psi)	132	36
Centre pressure of 21 m (30 psi)	98	27

Underlying assumptions in this study were that electric motors were 90% efficient and diesel fuel consumption of 0.3 L/kWh.
1 ML = 100 mm water applied to 1 ha

Seed potato production

Potato production is unique in that the seed is bulked up over a number of field generations to obtain sufficient seed to plant the processing crop. Our study calculated energy use and GHG emissions associated with i) growing the processing crop only, and ii) growing the processing crop with allowance for energy and GHG emissions associated with previous generations of seed potato production.

As seed tubers used for the production of the processing crop arise from a number of generations of seed crops, the contribution of the seed production process can also be estimated. In general, most crops in Australia are bulked up through four field generations (G1-G4) before tubers are released for production of the processing crop. The contribution of growing seed crops to the energy usage of the processing crop was estimated by calculating the energy and GHG emissions of the processing crop and assuming a contribution of 1/20th from the preceding seed generations. Thus the contribution from the G4 to the processing crop was estimated to be 1/20th that of the energy and emissions of the processing crop. In turn the contribution of the G3 to the G4 was assumed to be 1/20th the energy and emissions associated with the production of the G4. This was based on an assumption that 1 ha of seed crop would yield sufficient seed tubers to plant 20 ha of succeeding crop. Similarly the energy and GHG emissions associated with the grading, cutting and cool storage of seed potato was calculated for the generation which provided seed to the processing crop and a contribution of 1/20th of each of the previous generations was added. McCain Foods Australia in Tasmania, have recently adopted a three field generation scheme (G1-G3), so in this case only the contributions of the G2 and G3 were considered. For the purposes of our study only the contribution from G2 on was factored in. Due to the multiplier effect above, it was considered that the contribution of energy and GHG emissions to 1 ha of seed potato used for the processing crop which arose from laboratory and greenhouse production of minitubers, and of growing the small areas of G0 and G1 in the field, would be minimal.

4.4 Methods employed for Scenario 2

Scenario 2 was based on the studies in New Zealand of Wells (2001) and Barber (2004) as a basis for calculating energies and CO_2-e emissions associated with particular inputs. These studies make an allowance for the energy and emissions associated with the production and transport of inputs upstream of the farm, along with and GHG’s emitted during usage on farm (Table 4.7). These studies also allowed for the energy and emissions associated with the production of capital items (e.g. tractors, implements, buildings) distributed over the expected life of the item. In scenario 2, full cycle emission factors for Australia were utilised for particular inputs where it was available, including electricity (Table 4.8) and fuel (Table 4.9) (Department of Climate Change 2008). The emission factors for electricity in each State are different due to the predominance of hydroelectric generation in some States (e.g. Tasmania) and coal fired power stations in others (e.g. Victoria) (Table 4.8).

Table 4.7 Energy requirements and emissions associated with manufacture and distribution of fertilizer and pesticides used to assess energy usage and greenhouse gas emissions in Scenario 2.

Input	Energy use (MJ/kg nutrient, active ingredient or litre)	Emission factor (Kg CO_2/MJ)
Fertiliser[a]		
N	65	0.05
P	15	0.06
K	10	0.06
S	5	0.06
Lime	0.6	0.72
Pesticides[b]		
Herbicide (glyphosate and paraquat)	550	0.06
Other herbicides	310	0.06
Insecticide	310	0.06
Fungicide	210	0.06

[a] Includes energy requirements to manufacture fertilizer components and emissions from mining, manufacturing, packaging and distribution (Wells 2001).
[b] Includes energy and emissions associated with production, formulation, packaging and transport (Wells 2001).

Table 4.8 Emissions factors (EF) for consumption of purchased electricity in Australia. (Department of Climate Change 2008).

	EF for scope 2[a]	g CO_2-e/MJ	EF for full cycle	g CO_2-e/MJ
NSW, ACT	0.89	249	1.06	295
VIC	1.22	340	1.31	364
QLD	0.91	252	1.04	289
SA	0.84	233	0.98	272
WA	0.87	242	0.98	271
TAS	0.12	35	0.13	37
NT	0.69	190	0.79	221

[a]Scope 2 emission factors cover emissions from fuel combustion at power stations associated with consumption of purchased electricity from the grid.
[b]Full cycle emission factors include scope 2 emissions and emissions from the extraction, production and transport of fuels used to produce the purchased electricity and emissions associated with electricity lost in transmission and distribution on the way to the consumer

Table 4.9 Emission factors for transport fuels in Australia (Department of Climate Change 2008).

	Energy content (GJ/kL or MJ/L)	Emissions factors (scope 1)		Full fuel cycle emissions factors	
		g CO_2-e/MJ	t CO_2-e/kL	g CO_2-e/MJ	t CO_2-e/kL
Petrol	34.2	67.0	2.3	72.3	2.5
Diesel	38.6	69.8	2.7	75.2	2.9
Aviation gasoline	33.1	67.1	2.2	72.4	2.4

[a]Scope 2 emissions cover emissions from fuel combustion at power stations associated with consumption of purchased electricity from the grid.
[b]Full cycle emissions include scope 2 emissions and emissions from the extraction, production and transport of fuels.

4.5 Results

Scenario 1

Energy requirement associated with potato seed grading, cutting and cool storage

Energy consumption associated with the grading, cutting and cool storage of seed tubers for one hectare of processing crop in Tasmania was 848.3, 911.1 and 1351.0 MJ for Tas 1, Tas 3 and Tas 2, respectively (Table 4.10).

The energy consumption for seed potato in the Mallee and Lockyer Valley was estimated from the results from the Tasmanian seed facility, with adjustment for seed rate per hectare. Grading, cutting and cool storage of seed tubers sufficient for one hectare of crop was estimated to require 1351.0 and 1005.4 MJ/ha for Mallee and Lockyer Valley crops respectively (Table 4.10). The main inputs in terms of energy use were electricity and diesel used in transport (Table 4.10). The percentage of electricity use by different parts of the operation was estimated by the cool-store operator as: 90% coolstore, 4% grading, 4% cutting and 2% other. Based on electricity usage and tonnage, grading, cutting and cool storage was estimated to consume 1.699, 2.265 and 50.934 kWh/tonne. The difference in energy requirement between the different crop types for one hectare of seed, was mainly due to differences in seed rate (Table 4.9), with seed rates varying from 2.7 to 4.3 t/ha (Table 4.10).

Greenhouse gas emissions associated with potato seed grading, cutting and cool storage

The overall contribution of seed potato grading, cutting and storage in Tasmania to GHG emissions associated with planting 1 ha of processing crop equated to 40.2, 64.0 and 43.2 kg CO_2-e emissions per hectare for Tas 1, Tas 2 and Tas 3 respectively (Table 4.10). The estimation for Mallee and Lockyer Valley crops was 232.3 and 184.9 kg CO_2-e/ha respectively (Table 4.10). The main contributors were diesel and electricity use, with a small proportion due to LPG usage arising from forklift operations (Table 4.10). It should be noted that due to the predominance of hydro-electric power in Tasmania the GHG emissions from electricity use during seed handling were considerably lower than from grading, cutting and storage of seed potato in other States where coal-fired power stations are utilized (Table 4.10).

Inputs to production of the processing potato crop and onion and broccoli

Various inputs into the different case studies are summarized (Table 4.11). Diesel use in potato crops varied from 326.9 L in Lockyer Valley to 551.5 L in the Mallee crop. The latter reflected the use of a diesel pump for supply of irrigation water in comparison to electric pumps in other production systems and also to a relatively high input of irrigation water (7.5 ML/ha) in comparison to other potato systems (2.2-5.1 ML/ha) as a result of the hot climate and sandy soils in the Mallee region.

By comparison Lillywhite et al. (2007) reported an average of only 1.2 ML/ha in UK potato crops, perhaps reflecting climatic differences between UK and Australian production areas.

Table 4.10 Estimated GHG emissions associated with cutting and storage of seed potato sufficient to plant one hectare of crop for processing (Scenario 1).

Input	Amount used (MJ)	GHG emissions from storing and cutting sufficient seed to plant one hectare of processing crop (kg CO_2-e)
Tas 1 (2.7 tonnes/ha)		
Diesel use[a]	279.3	19.50
LPG use[a]	35.3	2.01
Electricity use[b]	533.7	18.68
Total/ha	848.3	40.19
Tas 2 (4.3 tonnes/ha)[a]		
Diesel use[a]	444.7	31.04
LPG use[a]	56.3	3.21
Electricity use[b]	850.0	29.75
Total/ha	1351.0	64.0
Tas 3 (2.9 tonnes/ha)[a]		
Diesel use[a]	300.0	20.94
LPG use[a]	37.94	2.16
Electricity use[b]	573.2	20.06
Total/ha	911.1	43.16
Mallee (4.3 t/ha)[a]		
Diesel use[a]	444.7	31.04
LPG use[a]	56.3	3.21
Electricity use[b]	850.0	198.03
Total/ha	1351.0	232.29
Lockyer Valley (3.2t/ha)[a]		
Diesel use[a]	331.0	23.11
LPG use[a]	41.9	2.39
Electricity use[b]	632.5	159.39
Total/ha	1005.4	184.88

[a] emission factors of 69.8 g and 57 g CO_2-e/MJ diesel and LPG respectively (Department of Climate Change 2008)

[b] Scope 2 emissions factors (g CO_2-e/MJ) for each state of 249 (NSW/ACT), 340 (VIC), 252 (QLD), 233 (SA), 242 (WA), 35 (TAS) and 190 (NT).

Note seed production for Mallee, South Australia and Lockyer Valley, Queensland was estimated on the basis of information from Tasmania.

The amount of nutrients applied varied between potato production systems from 163.8-495.5 kg/ha N, 39-476 kg/ha P, 201-900 kg/ha K (Table 5.11). The lowest rate of N (163.8 kg/ha N) occurred on the Mallee crop on sandy soils, where due to the potential loss of N through leaching, N was applied eight times during the season by fertigation in addition to a basal dressing. Higher P rates were associated with Tasmanian crops, probably due to the relatively high P-sorption capacity of Kraznosem soils. Interestingly, within Tasmanian Russet Burbank crops (Tas 1 and Tas 3) there was a wide range of N application rates (278 – 463.5 kg/ha N), reflecting some opportunities for efficiencies. By comparison Lillywhite et al. (2007) reported 200, 230 and 325 kg/ha of N, P and K in UK potato crops.

The two mainland case studies received lower amounts of herbicide and higher amounts of insecticide than the crops in Tasmania (Table 4.11). It would be expected that the cooler climate of Tasmania would have lower pest pressure than warmer parts of mainland Australia. Similarly the higher rainfall in Tasmania and the highly cropped nature of Tasmania soils might be expected to encourage weed growth and build up of weed banks. This is in contrast to some parts of the mainland where potato is in long rotations with pasture. Mainland crops also had lower fungicide requirements than the Russet Burbank crops in Tasmania. This reflects the more maritime climate of Tasmania, with higher potential for wet conditions which favour fungal pathogens including early and late blight. A notable exception was Tas 2 which had a more disease resistant variety than Russet Burbank, and which received less fungicide than all other crops. On average, Tas 2 crops received only two foliar fungicide applications in comparison to 12 for Russet Burbank in Tasmania.

Electricity use for irrigation varied from 532.4 kWh delivering 2.2 ML/ha in the Lockyer Valley to 1525 kWh delivering 5.1 ML/ha in Tas 3. Marketable yields of crops were generally high, with respondees indicating marketable yields of 55 t/ha, except in the Lockyer Valley where a marketable yield of 25 t/ha was quoted.

Onion and processing broccoli crops in Tasmania received lower inputs of N, P and K and required comparable quantities of diesel in comparison to potato crops in Tasmania (Table 4.11). Water requirements of onion and broccoli were 2.0 and 2.5 ML/ha, significantly lower than potato crops in Tasmania (4.6-5.1 ML/ha). Potato crops did not generally require liming, while onion received 2 t/ha.

Energy use in the processing crop and in onion and broccoli production

Energy requirements of potato crops varied widely from 26,249 MJ/ha in the Lockyer Valley to 55,458 MJ/ha in Tas 3 (Table 4.12). This compared with an energy input of 44,495 MJ/ha in potato production in the UK (Lillywhite et al. 2007). The main contributors to energy use in Australian potato crops were diesel (26.8-54.0%), nitrogen (20.6-39.3%), phosphorus (2.8-17.5%), potassium (4.6-13.6%) and electricity (0-9.9%).

Energy inputs associated with diesel use was highest in the Mallee crop, due predominately to the use of a diesel irrigation pump in this case study, in contrast to electric pumps in all others (Table 4.12). Energy associated with diesel use was lowest in the Lockyer Valley crop. Energy associated with diesel use was also low in Tas 2 and 3 crops which were cultivated using a one-pass system, while others were cultivated by a traditional multiple pass system. The energy efficiency of the former was slightly offset by the need to use a larger tractor to pull the one-pass tillage equipment (200 hp). Crops which had higher seeding rate (Tas 2 and Mallee) had a higher diesel usage and energy associated with transport of seed to farm.

Within Tasmania, energy use associated with the application of fertilizer was lower in Tas 1 than Tas 2 and 3 crops due to a lower rate of N and P, but partially offset by higher application rate of K and S (Table 4.11). By comparison, Mallee and Lockyer Valley crops had significantly lower inputs of N and P in comparison to Tasmanian crops (Tables 4.11 and 4.12). Similarly, the Lockyer Valley crop had lower inputs of K, while the Mallee crop had the highest input of K of all case studies (Table 4.11).

As noted above, Tas 2 crops had a lower energy input associated with application of fungicides than other crops, due to disease resistance in the variety Mac 1 (Table 4.12). Lockyer Valley crops had higher energy requirement in terms of insecticides and lower energy requirement in terms of herbicides than other crops, reflective of geographic differences (Table 4.12).

Within Tasmania, application of irrigation water was lowest in Tas 2 crops (4.6 ML/ha), intermediate in Tas 1 (5.1 ML/ha) and highest in Tas 3 (6.3 ML/ha) (Table 4.11). This led to lower energy associated with electricity usage (Table 4.11) and diesel usage in terms of tractor movements, for irrigation in Tas 2 in comparison to Russet Burbank (Tas 2 and 3) in Tasmania. By comparison there was a higher irrigation requirement (7.5 ML) in Mallee crops, and a lower requirement in Lockyer Valley (2.2 ML) (Table 4.11) indicative of climatic differences.

Other differences between the case studies included the use of aerial application of pesticides (helicopter and fixed wing) in some 60% of Tas 1 crops, whereas others employed ground spraying only.

The main agronomic operations associated with the greatest proportion of energy use in potato production were fertilizing (34.9-63.2%), harvesting (15.5-21.0%), irrigation (9.3-19.7%), cultivation (2.7-16.5%) and disease control (1.5-11.1% of total MJ/ha). (Table 4.13). The use of a resistant variety in the Tas 2 case study resulted in disease control making up a substantially lower proportion of energy input (1.5%) in comparison to other crops, in which it ranged from 3.3% of total energy input in the Mallee case study to 11.1% in Tas 1 (Table 4.13).

The use of a one-pass cultivation system led to cultivation making up a lower proportion of total energy input in Tas 2 and 3 crops (2.7 and 2.9) in comparison to other crops (5.5-16.5%).

Onion production had a similar energy use profile to potato with fertilizing (40.4%), harvesting (29.8%) and cultivation (9.5%) being the main contributors to energy usage. For broccoli, the main contributors to energy usage were harvesting (31.0%), fertilizing (27.4%) and planting (19.9%). The high energy requirement of planting in comparison to onion or potato is due to the planting of transplants. The ratio of energy output to input varied between potato crops from 3.16 in the Lockyer Valley crop to 4.60 in the Mallee crop. This compared with an energy output:input ratio of 3.34 for UK potato production

(Lillywhite et al. 2007) based on an input of 44,495 MJ/ha and an output of 44.7 t/ha (148,404 MJ/ha). Although the Lockyer Valley crop had the lowest input of energy (26,249 MJ/ha) it also had the lowest yield (25 t marketable crop) leading to a low energy output:input ratio. The amount of energy input per tonne marketable crop (energy productivity) varied from 721.5 MJ/tonne marketable crop in the Mallee to 1049.9 MJ/t in the Lockyer Valley crop. This compared with 995.4 MJ/t marketable crop for UK potato (Lillywhite et al. 2007).

Onion production within Tasmania consumed less energy (34,292 MJ/ha) than all of the Australian potato case studies (26,249 – 55,458 MJ/ha). Potato has a higher energy content (3320 MJ/t) than onion (1660 MJ/t), so despite a comparable yield of 54 t/ha, onion had a lower ratio of energy output : input (2.61) in comparison to potato crops (3.16-4.60). However, onion had the lowest energy input per tonne marketable crop (635 MJ/t). By comparison Lillywhite et al. (2007) reported onion crops in the UK to yield 41.6 t/ha (69,056 MJ/ha) and require energy inputs of 20,141 MJ/ha. This led to an lower energy requirement than Tasmanian onion (484.2 MJ/t marketable crop), and higher energy output:input ratio of 3.43. Broccoli also had a low energy content (1410 MJ/t) in comparison to potato, and coupled with a relatively lower yield (14 t/ha) had a low energy output:input (0.86) and higher energy input per tonne marketable crop (1641 MJ/t).

Greenhouse gas emissions from processing potato, onion and broccoli

The total GHG emissions for potato production ranged from 3820 to 9000 kg CO_2-e/ha for the Lockyer Valley and Tas 2 case studies respectively (Table 4.14). This compared with 7041 kg CO_2-e/ha for potato production in the UK (Lillywhite et al. 2007).

Table 4.11 Summary of major inputs into processing potato, onion and broccoli production (Scenario 1).

	Tas 1 (Tasmania)	Tas 2 (Tasmania)	Tas 3 (Tasmania)	Mallee (South Australia)	Lockyer Valley (Queensland)	Onion (Tasmania)	Processing broccoli (Tasmania)	Potato in New Zealand (Barber 2004)	Onion in New Zealand (Barber 2004)
Input:									
Diesel (L)	436.0	364.1	384.84	551.5	326.9	427.7	379.1	422	456
Nitrogen (kg/ha)	277.5	495.5	463.5	199.6	163.8	180	91.1	288	135
Phosphorus (kg/ha)	330.0	476.0	412	60.0	39.0	222.5	104.0	239	134
Potassium (kg/ha)	630.0	451.0	471.0	900.0	200.8	30	71.5	173	105
Sulphur (kg/ha)	105.0	0	0	168.0	0	30.1	0	114	77
Calcium (kg/ha)	0	0	0	211.0	79.8	2000[a]	0	720	977
Fungicide (kg a.i.)	17.5	3.3	20.9	5.5	10.6	9.02	0.4	32.0	35.7
Insecticide (kg a.i.)	0.2	0.4	0.4	0.2	2.6	0.7	0.1	3.4	3.0
Herbicide (kg a.i.)	4.3	3.2	3.2	1.9	0.6	4.0	2.7	1.3	11.4
Labour (hours)	55.4	45.2	53.1	57.6	57.6	117.6	61.8	-	-
Other fuel (L)	58.8	4.8	4.8	4.8	4.8	4.8	4.8	-	-
Electricity (kWh)	1234.2	1101	1525	0	532.4	484.0	247.5	360	78
Water (ML)	5.1	4.6	6.3	7.5	2.2	2.0	2.5		
Marketable crop (t/ha)	55	55	55	55	25	54	14	50	59

[a] as lime.

Table 4.12 Inputs of energy (MJ/ha) into the production of processing potato, onion and broccoli and the relative contribution (%) of each (Scenario 1).

	Tas 1		Tas 2		Tas 3		Mallee		Lockyer Valley		Onion (Tasmania)		Processing broccoli (Tasmania)	
Input:	MJ	%	MJ	%	MJ	%	MJ	%	MJ	%	MJ	%	MJ	%
Diesel	16828.3	33.5	14055.5	27.2	14854.9	26.8	21430.4	54.0	12617.8	48.1	16502.5	48.1	15072.3	65.6
Nitrogen	11377.5	22.7	20315.5	39.3	19003.5	34.3	8183.6	20.6	6713.8	25.6	7380.0	21.5	3735.7	16.3
Phosphorus	6270.0	12.5	9044.0	17.5	7828.0	14.1	1140.0	2.9	741.0	2.8	4218.0	12.3	1976.0	8.6
Potassium	3780.0	7.5	2706.0	5.2	2826.0	5.1	5400.0	13.6	1204.5	4.6	180.0	0.5	429.0	1.9
Sulphur	525.0	1.1	0.0	0.0	0.0	0.0	840.0	2.1	0	0	150.5	0.4	0	0
Ca	0	0	0	0	0	0	633.0	1.6	239.3	0.9	1200[b]	3.5	67.2	0.3
Fungicide	3672.7	7.3	627.5	1.2	4409.0	8.0	1170.6	3.0	1785.0	6.8	1513.7	4.4	27.8	0.1
Insecticide	42.8	0.1	74.9	0.1	74.9	0.1	42.8	0.1	554.7	2.1	147.0	0.4	567.1	2.5
Herbicide	1263.5	2.5	774.1	1.5	774.1	1.4	642.9	1.6	276.0	1.1	1019.6	3.0		
Labour	34.3	0.1	28.0	0.1	32.9	0.1	33.3	0.1	35.7	0.1	74.4	0.2	40.5	0.2
Other fuel	1951.9	3.9	164.2	0.3	164.2	0.3	164.2	0.4	164.2	0.6	164.2	0.5	164.2	0.7
Electricity	4443.1	8.9	3963.6	7.7	5490.0	9.9	0	0	1916.6	7.3	1742.4	5.1	891.0	3.9
Total (MJ/ha)	50189.1		51753.3		55457.5		39680.8		26248.5		34,292.2		22970.8	
Yield of marketable crop (t/ha)	55		55		55		55		25		54		14	
Total energy content in marketable crop (MJ/ha)[a]	182,600		182,600		182,600		182,600		83,000		89,640		19740	
Ratio energy output:input	3.64		3.53		3.29		4.60		3.16		2.61		0.86	
Energy productivity (MJ/t)	912.5		940.97		1008.3		721.5		1049.9		635.0		1640.8	

[a]Assume 3320 MJ/t (potato), 1660 MJ/t (onion) and 1410 MJ/t (broccoli) http://www.nal.usda.gov/fnic/foodcomp/search/

[b] as lime

Table 4.13 Energy (MJ/ha) associated with agronomic operations in the production of processing potato and onion and broccoli (Scenario 1).

	Tas 1		Tas 2		Tas 3		Mallee		Lockyer Valley		Onion (Tasmania)		Processing broccoli (Tasmania)	
Operation	MJ	%	MJ	%	MJ	%	MJ/ha	%	MJ	%	MJ	%	MJ	%
Fertilising	22467.8	44.8	32708.5	63.2	30258.4	54.6	16925.1	42.7	9167.9	34.9	13866.5	40.4	6302.3	27.4
Planting	1967.9	3.9	2134.2	4.1	1991.4	3.6	2132.5	5.4	2020.0	7.7	551.7	1.6	4566.5	19.9
Cultivation	4329.6	8.6	1521.7	2.9	1521.7	2.7	2162.4	5.5	4326.0	16.5	3247.1	9.5	2164.7	9.4
Weed control	1461.5	2.9	972.1	1.9	972.1	1.8	906.8	2.3	342.0	1.3	1574.3	4.6	839.3	3.7
Disease control	5592.4	11.1	759.4	1.5	5200.9	9.4	1302.6	3.3	2049.0	7.8	1999.1	5.8	486.3	2.1
Insect control	42.8	0.1	74.9	0.1	74.9	0.1	174.8	0.4	752.7	2.9	147.0	0.4	446.9	2.0
Harvesting	8608.0	17.2	8606.3	16.6	8606.3	15.5	8089.8	20.4	5508.8	21.0	10215.0	29.8	7108.7	31.0
Irrigation	5554.9	11.1	4811.9	9.3	6667.6	12.0	7822.7	19.7	1918.0	7.3	2527.4	7.4	891.8	3.9
Miscellaneous	164.2	0.3	164.2	0.3	164.2	0.3	164.2	0.4	164.2	0.6	164.2	0.5	164.2	0.7
TOTAL	50189.1		51753.3		55457.5		39680.8	100.0	26248.5		34292.2		22970.7	

Table 4.14 Estimated annual energy requirement (MJ/ha) for processing potato production to farm gate within Tasmania allowing for the contribution from previous generations of seed crops[a] (Scenario 1).

	Tas 1	Tas 2	Tas 3	Mallee	Lockyer Valley
Contribution from seed grading, cutting and cool storage:					
G4	848.3	-[b]	-[b]	1351.0	1005.4
G3[b]	42.4	1351.0	911.1	67.6	50.3
G2[b]	2.1	67.6	45.6	3.4	2.5
Contribution from growing potato:					
Processing crop	50189.1	51753.3	55457.5	39680.8	26,248.5
G4	2509.5	(2587.7)[b]	(2772.9)[b]	1984.0	1312.4
G3	125.5	129.4	138.6	99.2	65.6
G2	6.3	6.5	6.9	5.0	3.3
Total (MJ/ha)	53723.2	53307.7	56559.8	43191.0	28688.0
Energy in marketable crop (MJ/ha)	182,600	182,600	182,600	182,600.00	83000.00
Energy output:input	3.40	3.43	3.23	4.23	2.89
Energy productivity (MJ/t marketable crop)	976.8	969.2	1028.4	785.3	1147.5

[a] Based on an estimated 1/20 th contribution from preceding generations, due to the multiplication of seed tubers between generations. Contributions from G1 were considered insignificant and not included.
[b] Seed crops of Tas 2 and 3 are bulked up over three field generations while other crops are bulked over four field generations. Figure in parentheses was used to calculate the energy usage of preceding generations (G2 and G3) but was not used in calculation of the total energy usage.

The results of our study and that of Lillywhite et al. (2007) are comparable to that of Haile-Mariam et al. (2008) who measured GHG emissions from potato plots on fine sand in eastern Washington USA and calculated global warming contributions of 6028 kg CO_2-e/ha.

Onion production in Tasmania had a global warming potential of 4187 kg CO_2-e/ha in comparison to 3271 kg CO_2-e/ha in the UK (Lillywhite et al. 2007). Broccoli production had lower global warming potential (1367 kg CO_2-e/ha) than potato or onion (Table 4.15).

Allowing for a contribution from the production of potato seed, the GHG emissions from potato in Australia increased to between 4216 to 9091 kg CO_2-e/ha for Lockyer Valley and Tas 2 crops, respectively (Table 4.17).

Greenhouse gas emissions from fertilizer and residues

Total N_2O emissions from Australian potato crops ranged from 7.9 to 24.7 kg N_2O/ha or 2445 to 7659 kg CO_2-e in Lockyer Valley and Tas 2 case studies respectively (Table 4.15). Lillywhite et al. (2007) reported lower emissions (1224 kg N_2O/ha) from UK potato crops, although it must be emphasized that there were some differences in methods of calculating N_2O emissions between their study and ours (Tables 4.4 and 4.5).

The main contributors to estimated N_2O emissions were from N-fertiliser and N in crop residue (Table 4.15) with smaller amounts emitted from N that had leached or run-off and from atmospheric deposition. Total N fertilizer applied to Tas 1, Mallee and Lockyer Valley potato crops was significantly less than Tas 2 and 3 crops. This led to total N_2O emissions of 7.9 to 15.9 kg N_2O/ha in the former, and 24.7 and 23.4 kg N_2O/ha in Tas 2 and 3 respectively (Table 4.14). Broccoli and onion were estimated to emit 6.1 and 3.7 kg N_2O/ha, respectively. The form of N-fertiliser used also had an influence on the GHG emissions. Tas 2 and Tas 3 crops had higher inputs of urea, with consequently higher contributions of CO_2-e emissions per hectare from this source (Table 4.14).

The mean yield for most of the potato production practices was estimated by industry sources to be 60 t/ha, with a marketable yield of 55 t/ha, except for Lockyer Valley crop with an estimated 25 t/ha marketable crop (Table 4.14). This led to a similar amount of crop residue, and therefore equivalent estimated amounts of N_2O emitted from residue-N (4.7 kg/ha N_2O) for all potato crops, except Lockyer Valley (1.9 kg/ha N_2O) (Table 4.14). The lower amounts of residue in broccoli and lower rates of fertilizer N in broccoli and onion crops in comparison to potato led to lower emissions from residue N (2.0 and 0.02 kg/ha N_2O), respectively (Table 4.14).

Greenhouse gas emissions from liquid fuel and electricity use

GHG emissions from diesel use in different crop types were similar, ranging from 881 to 1496 kg/ha CO_2-e in Lockyer Valley and Mallee respectively (Table 4.14). Crops with lower seed rate benefited from reduced diesel use in transport of seed to the farm. In Tasmania, Tas 2 crops had a lower requirement than Tas 1 crops for cultivation, irrigation and fungicide application and consequently reduced diesel usage and emissions during these operations. A further 120 kg/ha CO_2-e was associated with Tas 1 crops as a result of the use of aviation fuel in aerial application of pesticides. The Mallee crop had the highest emissions from diesel use, as a result of using a diesel irrigation pump. Onion production in Tasmania had similar emissions from diesel to potato, while broccoli had significantly lower emissions from this source.

In Tasmania, the potato case studies had similar emissions in terms of electricity use for pumping of irrigation water, ranging from 138 to 192 kg/ha CO_2-e from Tas 2 and Tas 3 respectively (Table 4.14). The Lockyer Valley crop had a relatively high emission of 483 kg/ha CO_2-e from this source due to the use of coal fired electrical generation and consequent higher emission factor in this State. The Mallee crop had no emissions from this source due to the use of diesel powered irrigation pumps (Table 4.15). Onion and broccoli had lower emissions from electricity use due to the lesser requirement for irrigation in comparison to potato.

The use of diesel for irrigation (7.5 ML water/ha) in the Mallee crop consumed some 202.5 L/ha diesel (7816.5 MJ/ha) and, given an emission factor of 69.8 g CO_2/L, emitted 14.0 kg CO_2/ha. This equated to only 0.27% of the total 5215.4 kg CO_2-e/ha GHG emissions per hectare. By comparison, if electricity had been used for pumping irrigation water, assuming 99 kWh/ML (Maskey et al. 2007), a total of 742.5 kWh (2673 MJ) would have been required. This would have reduced energy usage by 5143.5 MJ/ha or 13.0%. However, give that the scope 2 emission factors for electricity use in South Australia are 233 g CO_2/MJ, the use of electricity would have emitted 622.8 kg CO_2/ha, leading to total GWP for the crop of 5824.1kg CO_2-e/ha, an increase of 608.7 kg CO_2-

e/ha over the diesel pump. Emissions from the electrical pump would comprise 11.9% of total CO_2 emissions.

Table 4.15 Contribution of processing potato, onion and broccoli production to GHG emissions and other pollutants per hectare (Scenario 1).

	Tas 1	Tas 2	Tas 3	Mallee	Lockyer Valley	Onion (Tasmania)	Processing broccoli (Tasmania)
Total crop (t/ha)	60	60	60	55	30	60	
Marketable crop (t/ha)	55	55	55	55	25	54	14
Inputs associated with emissions:							
Total N applied in fertiliser (kg/ha N)	277.5	495.5	463.5	199.6	163.8	180.0	91.1
Crop residue (dry matter)above and below ground (t/ha)	13.2	13.2	13.2	12.1	5.5	10.88	1.19
N remaining in crop residue (kg/ha N)	237.6	237.6	237.6	217.8	99.0	102.0	21.34
Amount of urea fertilizer applied (kg/ha urea)	125.0	287.5	287.5	0	0	250.0	250.00
Total P applied in fertilizer (kg/ha P)	330.0	476.0	412.0	60.0	39.0	222.5	104.0
Amount of lime applied (kg/ha)	0	0	0	0	0	2000	0
Diesel for cartage (L)	177.1	185.3	180.5	168.7	92.3	177.6	49.61
Diesel use by tractor (L)	258.9	178.8	204.3	180.3	234.6	250.1	329.5
Total diesel L (MJ)	436.0 (16,828.1)	364.1 (14,055.4)	384.8 (14,854.8)	349.0	326.9	16502.5	379.1 (14,633.6)
Petrol car L (MJ)	4.8 (164.1)	4.8 (164.1)	4.8 (164.1)	4.8	4.8	164.1	164.1
Aviation fuel L (MJ)	54 (1787.4)	0	0	0	0		0
Electricity use (MJ)	4443.1	3963.6	5490	0	1916.6	1742.4	891.0
Estimated greenhouse gas emissions:							
Nitrous oxide from N-fertilizer (kg/ha N_2O)	9.16	16.35	15.30	6.59	5.40	3.37	3.01
N-fertiliser lost by leaching and runoff (kg/ha N)	82.9	148.1	138.5	39.9	14.4	30.48	27.23
Nitrous oxide from leaching and runoff (kg/ha N_2O)	1.63	2.91	2.72	0.78	0.28	0.60	0.53
Nitrous oxide from residue N (kg/ha N_2O)	4.67	4.67	4.67	4.28	1.94	2.00	0.02
Amount of N-fertilizer volatilized into the atmosphere as NH_3-N and NO_x-N (kg/ha)	27.8	49.6	46.4	19.96	16.4	10.20	9.11
Nitrous oxide from deposition (kg/ha N_2O)[e]	0.44	0.78	0.73	0.31	0.26	0.16	0.14
Total nitrous oxide emissions kg/ha N_2O (kg/ha CO_2-e)[g]	15.89 (4925)	24.71 (7659)	23.41 (7258)	11.96 (3708.6)	7.89 (2445.4)	6.13 (1900.3)	3.70 (1147.0)
Emissions from urea (kg/ha CO_2)[f]	42.17	210.83	210.83	0	0	183.3	183.33
Emissions from lime (kg/ha CO_2)						880.0	
Emissions from diesel use (kg/ha CO_2-e)	1174.62	981.07	1036.87	1486.0	880.7	1151.9	26.46
Emissions from petrol use (kg/ha CO_2-e)	11.0	11.0	11.0	11.0	11.0	11.00	0.32
Emissions from Avgas use (kg/ha CO_2-e)	120.0	0	0	0	0	0	

Emissions from electricity use (kg/ha CO_2-e)	155.5	138.7	192.2	0	483.0	61.0	8.7
Total emissions of CO_2 (kg/ha CO_2)	1503.3	1341.6	1450.9	1506.8	1374.7	2287.1	218.8
Total global warming potential (kg/ha CO_2-e)	6429.0	9000.4	8708.4	5215.4	3820.1	4187.4	1366.8
Truck emissions (kg/ha):							
• Carbon monoxide	3.26	3.41	3.32	3.10	1.70	3.27	0.91
• Formaldehyde	0.14	0.15	0.15	0.14	0.08	0.14	0.04
• Nitrogen oxide	7.81	8.17	7.96	7.44	4.07	7.83	2.19
• PM_{10}	0.64	0.67	0.65	0.61	0.33	0.64	0.18
• Sulphur dioxide	0.66	0.69	0.67	0.63	0.34	0.66	0.19
• Total volatile organic compounds	0.72	0.75	0.73	0.68	0.37	0.72	0.20
Tractor emissions (kg/ha)							
• Carbon monoxide	8.34	5.76	6.58	5.92	7.55	8.05	10.61
• Formaldehyde	0.32	0.22	0.25	0.23	0.29	0.31	0.41
• Nitrogen oxide	13.56	9.37	10.71	9.64	12.29	13.11	17.27
• PM_{10}	1.44	1.00	1.14	1.02	1.31	1.39	1.84
• Sulphur dioxide	0.97	0.67	0.76	0.69	0.87	0.93	1.23
• Total volatile organic compounds	2.00	1.38	1.58	1.42	1.82	1.94	2.55
Car emissions (kg/ha)							
• Carbon monoxide	2.28	2.28	2.28	2.280	2.280	2.28	2.280
• Formaldehyde	0.003	0.003	0.003	0.003	0.003	0.003	0.003
• Nitrogen oxide	0.06	0.06	0.06	0.055	0.055	0.06	0.055
• PM_{10}	0.003	0.003	0.003	0.003	0.003	0.003	0.003
• Sulphur dioxide	0.003	0.003	0.003	0.003	0.003	0.003	0.003
• Total volatile organic compounds	0.008	0.008	0.008	0.075	0.075	0.08	0.075
Diesel pump emissions[a]							
• Carbon monoxide				2.45			
• Nitrogen oxide				17.00			
• PM_{10}				0.32			
• Sulphur dioxide				0.02			
• Total volatile organic compounds				0.28			
Contribution to acidification from:							
• NH_3	52.2	93.2	87.1	37.5	30.79	19.18	17.13
• NO_x	15.0	12.3	13.1	23.9	11.49	14.69	13.66
• SO_2	1.63	1.4	1.4	1.3	1.22	1.60	1.42
Total acidification potential (SO_2-e)[b]	68.8 (26.0)	106.8 (25.4)	101.7 (25.6)	62.8 (27.3)	43.5 (17.1)	34.5 (21.6)	32.2 (17.7)
Contribution to eutrophication from:							
PO_4^-	26.4	38.1	33.0	4.8	3.12	17.8	8.32
NH_3	9.16	16.35	15.30	6.6	5.40	3.37	3.01
NO_3^-	34.8	62.18	58.17	16.8	6.05	12.80	11.43
NO_x	2.79	2.29	2.43	4.4	2.13	0.01	2.54
Total eutrophication potential (PO_4^--e)[b]	46.8 (48.4)	80.82 (73.7)	75.90 (66.6)	32.6 (22.1)	16.7 (16.4)	33.98 (32.9)	16.98 (17.1)

[a] based on 99 kWh/ML and 7.5 ML/ha water giving 742.5 kWh.

[b] Figures are calculated taking into account Australian emission factors for NO_x and SO_2 from transport (NPI), while figures in parentheses are calculated as per Lillywhite et al. (2007).

The use of diesel for pumping irrigation water results in a significant reduction in CO_2 emissions, even in comparison to hydroelectric generation in Tasmania (Table 4.16). However, diesel is currently significantly more expensive per ML of water pumped than electricity and subject to diminishing supply and therefore not a sustainable alternative for reducing GHG emissions.

The total CO_2 emissions from liquid fuel and electricity usage in potato crops ranged from 1342 to 1507 kg CO_2/ha for Tas 2 and Mallee crops respectively. Onion crops had higher CO_2 emissions (2287 kg CO_2/ha), due principally to emissions associated with the use of lime (Table 4.14). Conversely, broccoli crops had low CO_2 emissions due to lower diesel and electrical use, although it should be noted that this example did not include emissions associated with production and transport of transplants to the farm.

Table 4.16 Comparison between electricity and diesel for pumping irrigation water in terms of energy usage and CO_2 emissions per megalitre of water.

	State	MJ/ML[b]	g CO_2/MJ[c]	kg CO_2/ML water
Electricity (98 kWh/ML)[a]	NSW/ACT	352.8	249.00	87.85
	VIC	352.8	340.00	119.95
	QLD	352.8	252.00	88.91
	SA	352.8	233.00	82.20
	WA	352.8	242.00	85.38
	TAS	352.8	35.00	12.35
Diesel (27L/ML)[a]		1042.2	69.8 g/L	1.88

[a] Assuming centre pivot with centre pressure of 21 m (30 psi) Maskey et al. (2007)
[b] Assume 3.6 MJ/kWh for electricity and 38.6 MJ/L for diesel
[c] Scope 2 emission factors for each State based on type of electricity generation (Department of Climate Change 2008)

Other pollutants

Eutrophication potential in potato crops ranged from 16.7 to 80.8 kg PO_4-e/ha, and acidification potential ranged from 43.5 to 106.8 kg SO_2-e in the Lockyer Valley and Tas 2 potato crops respectively (Table 4.15). The overall higher inputs of N and P fertilizer into Tas 2 and Tas 3 crops led to higher acidification and eutrophication potential in comparison to other potato crops (Table 4.16).

Table 4.17 Estimated GHG emissions (kg CO_2-e/ha) from processing potato production allowing for a contribution from the production of seed potato (Scenario 1).

	Tas 1	Tas 2	Tas 3	Mallee	Lockyer Valley
Seed grading, cutting and cool storage (kg CO_2-e/ha)					
G4	40.2	-[b]	-[b]	232.3	184.9
G3[a]	2.0	64.0	43.2	11.6	9.2
G2[a]	0.1	3.2	2.2	0.6	0.5
Processing crop (kg CO_2-e/ha)	6429.0	9000.3	8708.4	5215.4	3820.1
G4[a]	321.5	(450.0)[b]	(435.4)[b]	260.8	191.0
G3[a]	16.1	22.5	21.8	13.0	9.6
G2[a]	0.8	1.1	1.1	0.7	0.5
Total global warming potential (kg CO_2-e/ha)	6809.6	9091.2	8776.6	5734.4	3301.5

[a] Based on an estimated 1/20 th contribution from preceding generations, due to the multiplication of seed tubers between generations. Contributions from G1 were considered insignificant and not included.
[b] Seed crops of Tas 2 and Tas 3 are bulked up over three field generations while others are bulked up over four generations. For Tas 2 and Tas 3 crops, figures in parentheses were used to calculate emissions from preceding generations but were not included in the total.

The eutrophication and acidification potential for onion was 34.0 kg PO_4-e/ha and 34.5 kg SO_2-e, respectively, and for broccoli was 17.0 kg PO_4-e/ha and 32.2 kg SO_2-e/ha, respectively (Table 4.15). The above figures took into account Australian data for the emissions of acidifying pollutants from transport vehicles (SO_2 and NO_x). Using the calculations of Lillywhite et al. (2007) the acidification potential for Australian potato crops was lower, ranging from 17.1 to 27.3 kg SO_2-e/ha, in comparison to 13.8 kg SO_2-e/ha for UK crops (Lillywhite et al. 2007). Eutrophication potential ranged from 16.4 to 73.7 kg PO_4-e/ha in Australian potato crops, in comparison to 33.4 kg PO_4-e/ha in UK crops (Lillywhite et al. 2007). Using the methodology of Lillywhite et al. (2007), the acidification and eutrophication potentials for onion production in Tasmania were 21.6 kg SO_2-e/ha and 32.9 kg PO_4-e/ha respectively, in comparison to 8.3 kg SO_2-e/ha and 19.1 kg PO_4-e/ha respectively in the UK (Lillywhite et al. 2007). The higher figures for Tasmania arose from a higher estimated fuel usage (433 L/ha) in Tasmanian onion crops in comparison to U.K (139 L/ha) and higher rates of N and P (180 and 222.5 kg/ha, respectively) in Tasmanian onion crops in comparison to U.K. crops (125 and 150 kg/ha, respectively).

Other pollutants arising from potato production include general vehicle emissions such as carbon monoxide, formaldehyde, nitrogen oxide, sulphur dioxide, particles less than 10 μm in diameter and volatile organic compounds (Table 4.16). NEPC (2007) noted that in capital cities, reduction in emissions of oxides of nitrogen leading to nitrogen dioxide and ozone contributed to savings in health costs of $60 and $8,500/tonne, respectively, while reductions in emissions of particles (PM_{10}) lead to health cost savings of $232,000/tonne.

Pesticide environmental impact quotient (EIQ)

The pesticide EIQ for potato crops varied from 127.1 to 410.9/ha in Tas 2 and Tas 3 crops respectively (Table 4.18) in comparison to 134/ha for UK potato crops (Lillywhite et al. 2007). The lower rating of the Tas 2 arose from a higher degree of disease resistance in the variety grown in this case study, and consequently reduced applications of fungicides during the season. Mallee crops also had a relatively low EIQ rating (144.7/ha), with low use of fungicides, probably due to the dry conditions in this region which are less conducive to foliar fungal diseases. The Lockyer Valley crop had a higher EIQ rating for insecticides in comparison to other potato crops, indicating a higher pest pressure in this region (Table 4.18). Onion had an EIQ of 368.4/ha similar to that of the potato crops with the higher EIQ ratings, and higher than that reported for UK onion crops (140/ha) (Lillywhite et al. 2007). The EIQ pesticide rating for Tasmanian onion crops was 368.4 kg/ha in comparison to 140 kg/ha for U.K. crops (Lillywhite et al. 2007). The number of product applications of herbicide, fungicide and insecticide in Tasmanian crops was 13, 10 and 3 respectively and in U.K crops (Lillywhite et al. 2007) was 3, 8 and 3, respectively. This indicated the main difference in EIQ rating arose from the greater use of herbicides in Tasmanian crops in comparison to U.K. Processing broccoli in Tasmania had a low EIQ rating compared to onion and potato, due to low use of fungicides and the necessity to use mechanical weeding within the crop due to the lack of of selective herbicides.

Table 4.18 Environmental Impact Quotient (EIQ) for pesticides applied to crops of potato, broccoli and onion.

	EIQ and relative contribution of each pesticide to overall EIQ/ha (%)			Total EIQ/ha
	Fungicides	Herbicides	Insecticides	
Tas 1	281.5 (71.1%)	96.6 (24.4%)	17.7 (4.5%)	395.9
Tas 2	58.9 (46.3%)	53.0 (41.7%)	15.2 (12.0%)	127.1
Tas 3	342.7 (83.4%)	53.0 (12.9%)	15.2 (3.7%)	410.9
Mallee	79.9 (55.2%)	47.1 (32.6%)	17.7 (12.3%)	144.7
Lockyer Valley	165.8 (52.9%)	18.8 (6.0%)	128.7 (41.1%)	313.3
Onion (Tasmania)	200.5 (54.4%)	119.8 (32.5%)	48.0 (13.0%)	368.4
Broccoli (Tasmania)	6.1 (10.6%)	47.9 (83.2%)	3.6 (6.2%)	57.6

Scenario 2

Scenario 2 utilised emission factors from Wells (2001) which incorporated embodied energy of inputs (e.g. during manufacture). This scenario also included an allowance for the energy associated with infrastructure and machinery (Barber 2004). For fuel and electricity, the emissions factors for the full fuel emissions cycle calculated for Australia were used (Department of Climate Change 2008).

Potato seed grading, cutting and storage

Energy associated with the grading, cutting and cool storage of sufficient seed to plant one hectare of processing crop ranged from 1013.3 MJ for Tas 1 to 1613.3 MJ for Tas 2 and Mallee crops (Table 4.19). Grading, cutting and storage of seed contributed some between 57.3 and 291.0 kg CO_2-e/ha for Tas 1 and Mallee crops respectively (Table 4.18). The higher energy requirement and GHG emissions associated with Mallee and Lockyer Valley crops (Table 4.19) was principally due to the higher emissions associated with coal generation of electricity in South Australia and Queensland, in comparison to hydro-electric generation in Tasmania.

Table 4.19 Estimated GHG emissions associated with cutting and storage of seed potato sufficient to plant one hectare of processing crop (Scenario 2).

Input	**Amount used (MJ)**	**Emissions/MJ**	**GHG emissions from storing and cutting sufficient seed to plant one hectare of processing crop (kg CO_2-e)**
Tas 1 (2.7 tonnes/ha)[a]			
Diesel use	279.5	75.2 g CO_2-e /MJ diesel	21.01
LPG use	35.3	68.4 g CO_2-e/MJ LPG	2.41
Electricity use	533.6	Full cycle emission factor for electricity usage for Tasmania 37 g CO_2-e/MJ	19.74
Infrastructure and machinery	164.9	Emissions factor of 100 (buildings) and 80 g CO_2-e/MJ	14.12
Total/ha	1013.3 MJ		57.28 kg CO_2-e
Tas 2 (4.3 tonnes/ha)[a]			
Diesel use	444.7	75.2 g CO_2-e /MJ diesel	33.44
LPG use	56.3	68.4 g CO_2-e/MJ LPG	3.85
Electricity use	850.0	Full cycle emission factor for electricity usage for Tasmania 37 g CO_2-e/MJ	31.45
Infrastructure and machinery	262.5	Emissions factor of 100 (buildings) and 80 g CO_2-e/MJ	22.48
Total/ha	1613.5 MJ		91.22 kg CO_2-e
Tas 3 (2.9 tonnes/ha)[a]			
Diesel use	300.0	75.2 g CO_2-e /MJ diesel	22.56
LPG use	37.9	68.4 g CO_2-e/MJ LPG	2.60
Electricity use	573.2	Full cycle emission factor for electricity usage for Tasmania 37 g CO_2-e/MJ	21.21
Infrastructure and machinery	177.1	Emissions factor of 100 (buildings) and 80 g CO_2-e/MJ	15.17
Total/ha	1088.2 MJ		61.54 kg CO_2-e
Mallee (4.3 t/ha)			
Diesel use	444.6	75.2 g CO_2-e /MJ diesel	33.4
LPG use	56.4	68.4 g CO_2-e/MJ LPG	3.9
Electricity use	849.8	Full cycle emission factor for electricity usage for Queensland 272 g CO_2-e/MJ	231.1
Infrastructure and machinery	262.5	Emissions factor of 100 (buildings) and 80 g CO_2-e/MJ	22.5

Total/ha	1613.3 MJ		291.0 kg CO_2-e
Lockyer Valley (3.2 t/ha)			
Diesel use	331.0	75.2 g CO_2-e /MJ diesel	24.89
LPG use		68.4 g CO_2-e/MJ LPG	2.86
Electricity use	632.5	Full cycle emission factor for electricity usage for Queensland 289 g CO_2-e/MJ	182.8
Infrastructure and machinery	195.3	Emissions factor of 100 (buildings) and 80 g CO_2-e/MJ	16.7
Total/ha	1200.7		227.3

[a] Full cycle emissions (g CO_2-e/MJ) for each state are 295 (NSW/ACT), 364 (VIC), 289 (QLD), 272 (SA), 271 (WA) and 37 (TAS).

Production of processing potato and onion and broccoli

Tas 1

The total energy usage in Tas 1 was 64,896 MJ/ha, with the most energy intensive inputs being nitrogen (27.8%), diesel (25.9%), potassium (9.7%) and infrastructure and machinery (8.5%) (Table 4.20). The most energy intensive agronomic operations were fertilizing (46.7%), harvesting (13.2%), disease control (9.2%), irrigation (8.6%) and infrastructure and machinery (8.5%) (Table 4.21). The ratio energy output:input was 2.81 and energy productivity was 1179.9 MJ/t marketable crop (Table 4.20).

The contribution of seed crops to the energy usage of the processing crop was estimated by assuming a contribution of 1/20th from the previous generation. This was based on an assumption that 1 ha of seed crop would yield sufficient seed tubers to plant 20 ha of succeeding crop. The energy used in grading, cutting and storage of the G4 crop was calculated and the contribution from the G3 and G2 crop estimated as 1/20th of the energy associated with the succeeding generation (Table 4.22). Similarly, the energy associated with growing the processing crop was calculated and the contribution of the G2-G4 seed crops estimated as 1/20th of the energy associated with the succeeding generation (Table 4.22). In most production case studies (Tas 1, Mallee and Lockyer Valley) tubers are released for production of the processing crop following field multiplication through four generations (G1 to G4). No allowance was made for the production of minitubers and plantlets or for the G0 and G1 crops in the field as the latter take up minimal area and would contribute little to energy use of the processing crop. Allowing contributions from energy usage in the production of seed crops, the total energy use was estimated to be 69,378 MJ/ha with an energy input:output ratio of 2.63 and energy productivity of 1261 MJ/t marketable crop (Table 4.22).

Tas 2

The total energy usage was 69,984 MJ/ha, with the most energy intensive inputs being nitrogen (46.0%), diesel (20.1%), phosphorus (10.2%) and infrastructure and machinery (7.9%) (Table 4.20). The most energy intensive agronomic operations were fertilizing (63.6%), harvesting (12.3%), infrastructure and machinery (7.9%) and disease control (7.1%) (Table 4.21). The ratio energy output:input was 2.61 and energy productivity was 1272.4 MJ/t marketable crop (Table 4.20).

As above, the contribution of seed crops to the energy usage of the processing crop was estimated by calculating energy use associated with grading, cutting and storing the final seed crop and with growing the processing crop and assuming a contribution of 1/20th the energy usage of the succeeding generation/crop. Note that the seed production scheme for Tas 2 and Tas 3 releases tubers for processing production at G3. Because of this an estimation of the energy usage at G4 was made to allow calculation of the G2 and G3, however the former was not included in the sum of energy use (Table 4.22). Allowing contributions from energy usage from the seed crops, the total energy use was estimated to be 71,862 MJ/ha with an energy input:output ratio of 2.54 and energy productivity of 1307 MJ/t marketable crop (Table 4.22).

Tas 3

The total energy usage was 73,182 MJ/ha, with the most energy intensive inputs being nitrogen (41.2%), diesel (20.3%), phosphorus (8.4%) and infrastructure and machinery (7.6%) (Table 4.20). The most energy intensive agronomic operations were fertilizing (56.9%), harvesting (11.7%) and infrastructure and machinery (7.6%) (Table 4.21). The ratio energy output:input was 2.50 and energy productivity was 1331 MJ/t marketable crop (Table 4.20).

Allowing contributions from energy usage from the seed crops as for Tas 2 (above), the total energy use was estimated to be 74,517 MJ/ha with an energy input:output ratio of 2.45 and energy productivity of 1355 MJ/t marketable crop (Table 4.22).

Mallee

The total energy usage by processing potato production in the Mallee was 53,499 MJ/ha, with the most energy intensive inputs being diesel (39.8%), nitrogen (24.3%), potassium (16.8%) and infrastructure and machinery (10.4%) (Table 4.20). The most energy intensive agronomic operations were fertilizing (46.8%), harvesting (14.8%), irrigation (14.6%) and infrastructure and machinery (10.4%) (Table 4.21). The ratio energy output:input was 3.41 and energy productivity was 972.7 MJ/t marketable crop (Table 4.20).

Allowing contributions from energy usage from the seed crops, the total energy use was estimated to be 58,012MJ/ha with an energy input:output ratio of 3.0 and energy productivity of 1054.8 MJ/t marketable crop (Table 4.22).

Lockyer Valley

The total energy usage by processing potato production in the Queensland was 36,899 MJ/ha, with the most energy intensive inputs being diesel (34.2%), nitrogen (28.9%) and infrastructure and machinery (15.0%) (Table 4.20). The most energy intensive agronomic operations were fertilizing (36.7%), infrastructure and machinery (15.0%) harvesting (14.9%), cultivation (11.7%) and (Table 4.21). The ratio of energy output:input was 2.25 and energy productivity was 1476 MJ/t marketable crop (Table 4.20).

Allowing contributions from energy usage from the seed crops, the total energy use was estimated to be 40,105 MJ/ha with an energy input:output ratio of 2.1 and energy productivity of 1604 MJ/t crop (Table 4.22).

Onions: Tasmania

The total energy use during production of an onion crop in Tasmania was estimated as 44,143 MJ/ha with the most energy intensive inputs being diesel (37.4%), nitrogen (26.5%) and infrastructure and machinery (12.6%) (Table 4.20). This compared with an energy requirement of 50,140 MJ/ha for onion in New Zealand (Barber 2004), with fuel making up 39.6% and nitrogen 17.5% of the total (Barber 2004). The most energy intensive agronomic operations in Tasmanian crops were fertilizing (39.5%) and harvesting (23.1%) (Table 4.21). The energy output:input ratio for marketable crop in Tasmania was 2.03 with an energy productivity of 817.5 MJ/t marketable crop (Table 4.20). This compared with an energy output:input ratio of 2.1 and energy productivity of 850 MJ/t for onion in NZ (Barber 2004). Note our study did not factor in contributions from the production of seed.

Broccoli: Tasmania

The total energy consumption during production of processing broccoli was 30,912 MJ/ha, with diesel (47.3%), nitrogen (19.2%) and infrastructure and machinery (17.9%) being the main contributors (Table 4.20). In terms of agronomic operations, the greatest consumers of energy were fertilising (27.0%), harvesting (22.9%), infrastructure and machinery (17.9%) and planting (14.8%) (Table 4.21). The energy content of the harvested heads was 19,740 MJ/ha, with an energy output:input ratio of 0.64 and energy productivity 2208 MJ/t marketable crop (Table 4.20). Note this study did not factor in contributions from the nursery production of transplants.

Comparison of energy inputs into potato crops within Australia with other crop types, and with potato and onion production in New Zealand

Barber (2004), reported similar usage of diesel (422 L/ha) to most of the Australian case studies (327-552 L/ha) (Table 4.11). There was considerable variation in the amount of nutrients applied to crops in the Australian case studies, e.g. nitrogen (164-496 kg/ha N), phosphorus (39-476 kg/ha K), potassium (201-900 kg/ha K), and sulphur (0-168 kg/ha S). This compared with 288, 239, 173 and 114 kg/ha N, P, K and S respectively in the NZ case study (Barber 2004) (Table 4.11). Variations in the amount of nutrients in the Australian study may be partially due to soil type and climate. For example higher levels of P are applied to Kraznosem soils in Northern Tasmania to account for high P-sorption. However, there is likely to be considerable gain to growers and the environment to adopting strategies which better target nutrient use to plant growth (e.g. use of nutrient budgeting calculators, soil and sap testing). The amount of active ingredient of fungicides and insecticides was 32.0, and 3.4 kg/ha a.i. respectively in the NZ potato study. This was higher than in the Australian case studies with fungicides and insecticides ranging from 3.3 – 20.9 and 0.2-2.6 and kg/ha a.i. respectively. Barber (2004) noted that his study had been conducted in a wet and humid year and that fungicide use would normally be a quarter to a fifth of the quoted amount. Conversely, herbicide use in the New Zealand study (1.3 kg/ha a.i.) was similar to Australian crops (0.6-4.3 kg/ha a.i.), although tended to be lower than in Tasmanian potato. Electricity use in the New Zealand potato study was low (360 kWh/ha) in comparison to Australian crops which used electricity for irrigation (532-1525 kWh/ha) (Table 4.11), again probably reflecting the wet conditions during the NZ study. Yield of potato was similar in the New Zealand study (50 t/ha) and most of the Australian case studies (25-55 t/ha) (Table 4.11).

In terms of energy use, while our study was based on the same methodology of Barber (2004) some differences were apparent, in that different methodology was used for calculation of energy associated with fuel and electricity, and some allowance was made for transport of goods and services to the potato field. Despite this the two studies gave similar results. Energy use in the production of potato in Australia was similar to that reported by Barber (2004) in New Zealand, and reflected the level of inputs above (Table 4.11). The NZ crop had an energy requirement of 60,030 MJ/ha (without contributions from pack-house and office). By comparison the energy inputs into Australian potato crops ranged from 36,900 to 73,182 MJ/ha for Lockyer Valley crop and Tas 3, respectively. Within Tasmania, Tas 2 and Tas 3 had a lower diesel requirement and Tas 1 a higher requirement than the NZ crop, reflecting the advantage of the one-pass cultivation system of Tas 2 and Tas 3. Conversely Tas 2 and Tas 3 crops had a higher nitrogen input, and other Australian crops a lower input than the NZ crop. The Tasmanian crops had a higher energy input and the Mallee and Lockyer Valley crops a lower energy input in terms of P and K than the NZ crop (Table 4.20). The NZ crop had a lower energy input in terms of K, in comparison to all Australian crops (Table 4.20). Australian crops had a lower requirement in fungicide, insecticide, but a higher requirement in herbicide than the NZ crop. Barber (2004) noted that his study had been conducted in a wet and humid year and that fungicide use would normally be a quarter to a fifth of the quoted amount. This would indicate that the NZ crop would normally require a lesser amount of fungicide to the Tas 1 and Tas 3 crops, and slightly more fungicide than the Tas 2 crops in Tasmania. Electricity requirements in Tasmania crops were higher than in the NZ study. Again, this may have been due to the exceptionally wet year indicated by Barber (2004) leading to a low requirement for irrigation water in the NZ crop in the study season.

The major contributors to energy consumption in potato production in NZ were nitrogen (31.2%) and diesel (29.2%), similar to Australian potato crops. Energy associated with fungicide use in the NZ study made up 11.2% of total energy requirement which was higher than in the Australian case studies, again reflecting the un-seasonally wet conditions during the NZ study (Barber 2004) (Table 4.20).

The ratio of energy output:input for the NZ crop was 2.7, similar to that of the Australian crops (2.3-3.4). The energy productivity (MJ input/tonne output) was also similar between the NZ crop (1200.6 MJ/t) and the Tasmanian crops (927-1476 MJ/t) (Table 4.20).

In comparison to onion in New Zealand (Barber 2004), the Tasmanian onion crop had similar inputs of diesel, higher inputs of N and P, and lower inputs of fungicide, insecticide and herbicide (Table 4.20). Onion production in New Zealand required an energy input of 50,140 MJ/ha (without contributions from pack-house and office), an overall energy ratio of 2.1 and an energy productivity of 850 MJ/tonne. The Tasmanian case study gave similar figures of 44,143 MJ/ha, an energy ratio of 2.0, and energy productivity of 817.5 MJ/t. Barber (2004) noted that the major contributors of energy use in onion production were diesel (40%), fertilizer (25%), agrichemicals (24%), capital (10%) and electricity (1%). This compared with the Tasmanian case study of diesel (37.4%), fertilizer (37.8%), agrichemicals (7.9%), infrastructure and machinery (12.6%) and electricity (4.0%). As above Barber (2004) noted that the year of his study was exceptionally wet. This may have contributed to the higher proportion of energy usage in agrichemicals and lower proportion of electrical use (e.g. irrigation) in the NZ study in comparison to the Tasmanian case study.

Onion production in Tasmania had similar requirement for energy inputs and broccoli lower requirement in comparison to potato (Table 4.20). No allowance was made for contributions to energy usage from seed production in onion or transplant production in broccoli in our study. Despite similar yield, onion had a lower energy output:input ratio (2.0) in comparison to potato (2.3-3.4) principally due to the low energy content of onion (1660 MJ/t) in comparison to potato (3320 MJ/t) (Table 4.20). However, onion had a lower energy productivity requirement (818 MJ/t) in onion in comparison to potato (973-1476 MJ/t). Broccoli had a energy output:input ratio of 0.6, considerably lower than potato or onion, due to relatively low yield of marketable product (14 t/ha) and lower energy content (1410 MJ/t) (Table 4.20). Although broccoli production in Tasmania was estimated to require less energy input (30,912 MJ/ha) than potato or onion (Table 4.20), the lower marketable yield of this crop led to a relatively high energy productivity (2208 MJ/t) in comparison to potato or onion (Table 4.20).

Greenhouse gas emissions

Tas 1

Total greenhouse gas emissions for Tas 1 were estimated at 4009.4 kg CO_2-e/ha, with the greatest contributions from diesel use (31.6%), nitrogen (22.5%), infrastructure and machinery (11.5%) potassium (9.4%) (Table 4.23). The agronomic operations associated with the greatest GHG emissions were fertilizing (40.7%), harvesting (16.1%), infrastructure and machinery (11.5%), disease control (9.6%) and cultivation (9.1%) (Table 4.24).

As for energy usage an allowance was made for the contribution of seed potato to the total GHG emissions by assuming preceding generations contributed 1/20th the amount of succeeding generations. Allowing for contributions in GHG emissions from the seed crops, the total GHG emissions associated with 1 ha of processing potato was estimated as 4280.7 kg CO_2-e/ha (Table 4.25).

Tas 2

Total greenhouse gas emissions for Tas 2 were estimated at 4130.9 kg CO_2-e/ha, with the greatest contributions from, nitrogen (39.0%), diesel use (25.6%), infrastructure and machinery (11.2%), and phosphorus (10.4%) (Table 4.23). The agronomic operations associated with the greatest GHG emissions were fertilizing (57.1%), harvesting (15.6%), and infrastructure and machinery (11.2%) (Table 4.24).

As for energy usage an allowance was made for the contribution of seed potato to the total GHG emissions by assuming preceding generations contributed 1/20th the amount of succeeding generations. Allowing for contributions in GHG emissions from the seed crops, the total GHG emissions associated with 1 ha of processing potato was estimated as 4236.9 kg CO_2-e/ha (Table 4.25).

Tas 3

Total greenhouse gas emissions for Tas 3 were estimated at 4320.6 kg CO_2-e/ha, with the greatest contributions from nitrogen (34.9%), diesel use (25.9%), infrastructure and machinery (10.7%) phosphorus (8.6%) (Table 4.23). The agronomic operations associated with the greatest GHG emissions were fertilizing (51.0%), harvesting (14.9%) and infrastructure and machinery (10.7%) (Table 4.24).

As for energy usage an allowance was made for the contribution of seed potato to the total GHG emissions by assuming preceding generations contributed 1/20th the amount of succeeding generations. Allowing for contributions in GHG emissions from the seed crops, the total GHG emissions associated with 1 ha of processing potato was estimated as 4396.6 kg CO_2-e/ha (Table 4.25).

Table 4.20 Contribution of inputs to energy usage in processing potato, onion and broccoli production (Scenario 2).

	Tas 1		Tas 2		Tas 3		Mallee		Lockyer Valley		Onion (Tasmania)		Broccoli (Tasmania)		Processing potato in NZ (Barber 2004)	
	(MJ/ha)	(%)	(MJ/ha)	(%)	(MJ/ha)	(%)	(MJ/ha)	(%)	(MJ/ha)	(%)	(MJ/ha)	(%)	(MJ/ha)	(%)	(MJ/ha)	(%)
Diesel	16,828.1	25.9	14,055.4	20.1	14,854.8	20.3	21,289.6	39.8	12,617.8	34.2	16,507.3	37.4	14,633.7	47.3	17,530[a]	29.2
N	18,037.5	27.8	32,207.5	46.0	30,127.5	41.2	12,974.0	24.3	10,643.8	28.9	11,700.0	26.5	5922.5	19.2	18,700	31.2
P	4950.0	7.6	7,140.0	10.2	6180.0	8.4	900.0	1.7	585.0	1.6	3337.5	7.6	1560.0	5.1	3,580	6.0
K	6300.0	9.7	4,510.0	6.4	4710.0	6.4	9000.0	16.8	2007.5	5.4	300.0	0.7	715.0	2.3	1,730	2.9
S	525.0	0.8	0.0	0.0	0.0	0.0	840.0	1.6	0	0	150.5	0.3	0	0	570	0.9
Ca (lime)	0	0	0	0	0	0	600.0[d]	1.1	47.9	0.1	1200.0	2.7	0	0	0	0
Fungicide	3683.4	5.7	685.7	1.0	4398.0	6.0	1148.7	2.2	2231.3	6.1	1894.2	4.3	84.0	0.3	6,720	11.2
Insecticide	62.0	0.1	108.5	0.2	108.5	0.1	62.0	0.1	816.5	2.2	211.1	0.5	41.0	0.1	1,040	1.7
Herbicide	2209.0	3.4	1,610.1	2.3	1610.1	2.2	980.8	1.8	330.0	0.9	1397.0	3.2	1361.5	4.4	530	0.9
Electricity	4443.1	6.8	3,963.6	5.7	5490.0	7.5	0.00	0.0	1916.6	5.2	1742.4	4.0	891.0	2.9	2,930	4.9
Other fuel	2318.8	3.6	164.2	0.2	164.2	0.2	164.2	0.3	164.2	0.4	164.2	0.4	164.2	0.5	880	1.5
Infrastructure and machinery	5539.3	8.5	5,539.3	7.9	5539.3	7.6	5539.3	10.4	5539.3	15.01	5539.3	12.6	5539.3	17.9	5390	8.9
Total for processing crop	64896.14		69,984.1		73,182.4		53498.6		36899.7		44143.4		30912.0		60,030[b]	
Total energy content in marketable crop MJ/ha	182,600		182,600		182,600		182,600		83,000		89,640		19,740		161,500 (166,000)[c]	
Energy output:input	2.81		2.61		2.50		3.41		2.25		2.03		0.64		2.69 (2.77)[c]	
Energy productivity (MJ input/tonne)	1179.9		1272.4		1330.6		972.7		1476.0		817.5		2208.0		1200.6	

[a] value includes amount for lubricants
[b] value without allowance for packhouse/office
[c] note Barber (2004) quoted a 50t/ha yield and used a value of 3,230 MJ/t. In this study we used 3320 MJ/t (http://www.nal.usda.gov/fnic/foodcomp/search/), and have recalculated (number in parentheses).
[d] gypsum (assume same MJ as lime)

Table 4.21 Contribution of agronomic operations to energy usage in processing potato, onion and broccoli production (Scenario 2).

	Tas 1		Tas 2		Tas 3		Mallee		Lockyer Valley		Onion (Tasmania)		Broccoli (Tasmania)	
	(MJ/ha)	(%)	(MJ/ha)	(%)	(MJ/ha)	(%)	(MJ/ha)	(%)	(MJ/ha)	(%)	(MJ/ha)	(%)	(MJ/ha)	(%)
Fertilising	30,326.7	46.7	44,499.4	63.6	41,617.3	56.9	25,040.0	46.8	13,552.4	36.7	17,423.3	39.5	8360.0	27.0
Planting	1966.3	3.0	2130.7	3.0	1987.9	2.7	2130.9	4.0	2017.1	5.5	555.8	1.3	4562.5	14.8
Cultivation	4323.2	6.7	1520.8	2.2	1520.8	2.1	2161.6	4.0	4323.2	11.7	3242.4	7.4	2161.6	7.0
Weed control	2405.9	3.7	1806.9	2.6	1806.9	2.5	1243.3	2.3	395.6	1.1	1922.0	4.4	1631.7	5.3
Disease control	5969.2	9.2	816.9	1.2	5185.5	7.1	1279.9	2.4	2493.7	6.8	2123.9	4.8	280.9	0.9
Insect control	62.0	0.1	108.5	0.2	108.5	0.1	193.2	0.4	1013.3	2.8	440.7	1.0	237.8	0.8
Harvesting	8588.5	13.2	8588.5	12.3	8588.5	11.7	7929.7	14.8	5484.3	14.9	10205.8	23.1	7083.1	22.9
Irrigation	5550.9	8.6	4808.9	6.9	6663.4	9.1	7816.5	14.6	1916.6	5.2	2526.0	5.7	891.0	2.9
Infrastructure and machinery	5539.3	8.5	5539.3	7.9	5539.3	7.6	5539.3	10.4	5539.3	15.0	5539.3	12.6	5539.3	17.9
Miscellaneous	164.2	0.3	164.2	0.2	164.2	0.2	164.2	0.3	164.16	0.4	164.2	0.4	164.2	0.5
Total for processing crop	64896.1		69,984.2		73,182.4		53498.6		36,899.7		44,143.4		30,912.0	

Table 4.22 Estimated annual energy requirement (MJ/ha) for processing potato production to farm gate within Tasmania allowing for the contribution from previous generations of seed crops[a] (Scenario 2).

	Tas 1	Tas 2	Tas 3	Mallee	Lockyer Valley
Seed grading, cutting and cool storage					
G4	1013.3	-[b]	-[b]	1613.3	1200.7
G3[a]	50.7	1613.5	1088.2	80.7	60.0
G2[a]	2.5	80.7	54.4	4.0	3.00
Processing crop	64,896.1	69,984.2	73,182.4	53498.6	36899.7
G4[a]	3244.8	(3499.2)[b]	(3659.1)[b]	2674.9	1845.0
G3[a]	162.2	175.0	183.0	133.7	92.3
G2[a]	8.1	8.8	9.2	6.7	4.6
Total (MJ/ha)	69,377.8	71,826.0	74,517.1	58011.9	40,105.3
Total energy content in marketable crop MJ/ha[c]	182,600	182,600	182,600	182,600	83,000
Energy output:input	2.63	2.54	2.45	3.00	2.07
Energy productivity (MJ/t)	1261.41	1306.6	1354.9	1054.8	1604.2

[a] Based on an estimated 1/20 th contribution from preceding generations, due to the multiplication of seed tubers between generations. Contributions from G1 were considered insignificant and not included.
[b] Seed crops of Tas 2 and Tas 3 are bulked up over three field generations in comparison to others which are bulked up over four field generations. Figure in parentheses was used to calculate the energy usage of preceding generations (G2 and G3) but was not used in calculation of the total energy usage.
[c] Based on 3320 MJ/t marketable crop

Mallee

Total greenhouse gas emissions for processing potato production in the Mallee were estimated at 3787.2 kg CO_2-e/ha, with the greatest contributions from diesel use (39.1%), nitrogen (17.1%), potassium (14.3%), infrastructure and machinery (12.2%) and calcium (11.4%) (Table 4.23). The agronomic operations associated with the greatest GHG emissions were fertilizing (46.3%), harvesting (15.8%) and irrigation (12.4%) and infrastructure and machinery (12.2%) (Table 4.24). Allowing for contributions in GHG emissions from the seed crops, the total GHG emissions associated with 1 ha of processing potato was estimated as 4292.7 kg CO_2-e/ha (Table 4.25).

Lockyer Valley

Total greenhouse gas emissions for processing potato production in the Queensland were estimated at 2901 kg CO_2-e/ha, with the greatest contributions from diesel use (32.7%), electricity (19.1%) nitrogen (18.3%), infrastructure and machinery (15.9%) (Table 4.23). The agronomic operations associated with the greatest GHG emissions were fertilizing (25.6%), irrigation (19.1%), infrastructure and machinery (15.9%) harvesting (14.2%), and cultivation (11.2%). (Table 4.24).

Allowing for contributions in GHG emissions from the seed crops, the total GHG emissions associated with 1 ha of processing potato was estimated as 3293 kg CO_2-e/ha (Table 4.25).

Onions: Tasmania

Total greenhouse gas emissions from onion were 3661.3 kg CO_2-e/ha, with diesel (33.9%), lime (23.6%), nitrogen (16.0%) and infrastructure and machinery (12.6%) being the main contributors (Table 4.23). In terms of agronomic operations, fertilising (47.2%), harvesting (21.0%) and infrastructure and machinery (12.6%) were the major contributors to GHG emissions (Table 4.24). Note this study did not factor in contributions from the nursery production of transplants.

Broccoli: Tasmania

Total greenhouse gas emissions from processing broccoli were 2128.8 kg CO_2-e/ha, with diesel (51.7%), infrastructure and machinery (21.7%) and nitrogen (13.9%) being the main contributors (Table 4.23). In terms of agronomic operations, harvesting (25.0%), infrastructure and machinery (21.7%), fertilising (20.9%) and planting (16.1%) were the major contributors to GHG emissions (Table 4.24). Note this study did not factor in contributions from the nursery production of transplants.

Comparison of GHG emissions in Australian potato with other crops, and with potato and onion production in New Zealand

While this study was based on the same methods of Barber (2004), a different method was used for emission factors for fuel and electricity, and some allowance was made for transport of goods and services to the potato field in our study. Despite this the two studies gave similar results. Total greenhouse gas emissions for the case studies of potato production in Australia ranged from 2901 to 4321 kg CO_2-e/ha for Lockyer Valley and Tas 3, respectively (Table 4.25), in comparison to 3925 kg CO_2-e/ha in New Zealand (Barber 2004).

The main components of GHG emissions in NZ potato were fertilizer (38.9%), diesel (30.6%), agrichemicals (12.7%), capital (11.5%) and electricity (6.3%), with a total emission of 1527, 1202, 497, 450 and 249 kg CO_2-e/ha respectively (Barber 2004). By comparison, the main components of GHG emissions in Australian potato production were fertilizer (24.9-55.9%), diesel/fuel (25.9-39.5%), agrichemicals (3.5-8.9%), infrastructure and machinery (10.7-15.9%) and electricity (0-19.1%). As discussed previously, the wet season in which Barber (2004) conducted their study would have increased the contribution from agrichemicals in comparison to more representative years. As a proportion of electrical generation in New Zealand is hydro-electric it might be expected that the contribution of electricity to GHG emissions might be similar in NZ to the Tasmanian situation rather than mainland Australia where coal generation is commonly used.

Onion production in NZ gave rise to 3371-3535 kg CO_2-e/ha, in comparison to the Tasmanian case study (3661 kg CO_2-e). The main contributors in the NZ study were diesel/fuel (34.0-39.6%), fertilizer (27.6-33.1%), agrichemicals (19.7-21.5%), capital (10.9-12.7%) and electricity (0.03-0.48%). In the Tasmanian case study relative contributions of GHG emissions were diesel/fuel (34.2%), fertilizer (45.7%), agrichemicals (5.7%), infrastructure and machinery (12.6%) and electricity (1.8%).

The broccoli case study in Tasmania produced lower GHG emissions (2129 kg CO_2-e/ha) than potato, while the onion case study had lower emissions than all potato crops except for the Mallee case study.

4.6 General Discussion

National GHG emissions and climate change based on Scenario 1

Australian national statistics of the area of potato production in each State was used in this assessment (see Section 3, above). The analysis included both processed and fresh market potatoes, and for the purposes of the assessment a broad assumption was made that growth of processing crops would be similar in most aspects to fresh production.

Due to difficulty in sourcing case studies from each State within the timeframe of the project, production in New South Wales and Victoria was assumed to be similar to the Tas 1 case study in Tasmania. Production in Western Australia was assumed to be similar to the Mallee case study, with adjustment for pumping water with electricity rather than diesel, as this was assumed to be more common. Allowance was made for differences between States in emission factors associated with electricity (Department of Climate Change 2008) and leaching of N-fertiliser (NGGIC 2007). Within Tasmania, 800 ha was attributed to Tas 2 and Tas 3 case studies, and the remainder to Tas 1.

The total area involved in production of potato in Australia was 34,096 ha, with average yields between 25-46 t/ha (Table 4.26). On the basis of average yield per State, potato production in Australia not accounting for seed potato production was estimated to release 0.17 t CO_2-e/tonne crop or 6.20 t CO_2-e/ha (Table 4.26). Allowing for a contribution from seed potato, potato production was estimated to release 0.19 t CO_2-e/tonne crop or 6.7 t CO_2-e/ha (Table 4.26).

The estimated total annual Global Warming Potential for the potato industry was 211,497 t CO_2-e, or 227,332 t CO_2-e allowing for the contribution from seed production (Table 4.26). A total of 476 t N_2O (147,596 t CO_2-e) was produced, contributing 69.8% of total global warming potential of the industry (Table 4.26).

Within each State, potato production contributed between 0.02% (Queensland) and 2.6% (South Australia) of State emissions due to Agriculture, Forestry and Fisheries, or 0.02 (Queensland) to 3.0% (South Australia) allowing for a contribution from seed production (Table 4.26).

In 2006, Australia's net greenhouse gas (GHG) emissions from all sectors of the economy equated to some 576.0 million tonnes of CO_2 equivalents (Mt CO_2-e), with the greatest emissions from the electricity gas and water sector (35.5% of national emissions) (Anon 2008a). The agriculture, fish and forestry sector was second highest with 32.7% of national emissions (136 Mt CO_2-e). From estimates based on Scenario 1, the field production component of the potato industry in Australia contributes some 0.16% of the agriculture, fish and forestry sector emissions for Australia and 0.04% of Australia's total net GHG emissions.

National GHG emissions and climate change based on Scenario 2

Using methods based on Wells (2001) and Barber (2004), the potato industry within Australia was estimated to contribute 150,576 t CO_2-e or an average of 4.42 t CO_2-e/ha annually (Table 4.27). This equated to an average of 0.11% of national annual GHG emissions attributed to the Agriculture, Fish and Forestry sector (136 Mt CO_2-e in 2006) and 0.03% to the national annual GHG emissions from all sectors (576 Mt CO_2-e in 2006.

Table 4.23 Contribution of inputs to greenhouse gas emissions (kg CO_2-e/ha) for processing potato, onion and broccoli (Scenario 2).

	Tas 1		Tas 2		Tas 3		Mallee		Lockyer Valley		Onion (Tasmania)		Broccoli (Tasmania)		Processing potato in NZ (Barber (2004)
	kg CO_2-e/ha	(%)	kg CO_2-e/ha	(%)	kg CO_2-e/ha	(%)	kg CO_2-e/ha	(%)	kg CO_2-e/ha	(%)	kg CO_2-e/ha	(%)	kg CO_2-e/ha	(%)	kg CO_2-e/ha
Diesel	1265.5	31.6	1057.0	25.6	1117.1	25.9	1482.1	39.1	948.9	32.7	1241.4	33.9	1100.5	51.7	1020
N	901.9	22.5	1610.4	39.0	1506.4	34.9	648.7	17.1	532.2	18.3	585.0	16.0	296.1	13.9	
P	297.0	7.4	428.4	10.4	370.8	8.6	54.0	1.4	35.1	1.2	200.3	5.5	93.6	4.4	
K	378.0	9.4	270.6	6.6	282.6	6.5	540.0	14.3	120.5	4.2	18.0	0.5	42.9	2.0	
S	15.8	0.4	0.0	0.0	0.0	0.0	25.2	0.7			4.5	0.1	0	0	1527
Ca (Lime)	0	0	0	0	0	0	432.0[a]	11.4	34.5	1.2	864.0	23.6	0	0	
Fungicide	221.0	5.5	41.1	1.0	263.9	6.1	68.9	1.8	133.9	4.6	113.6	3.1	5.0	0.2	
Insecticide	3.7	0.1	6.5	0.2	6.5	0.2	3.7	0.1	49.0	1.7	12.7	0.4	2.5	0.1	
Herbicide	132.5	3.3	96.6	2.3	96.6	2.2	58.9	1.6	19.8	0.7	83.8	2.3	81.7	3.8	497
Electricity	164.4	4.1	146.7	3.6	203.1	4.7	0.0	0.0	553.9	19.1	64.5	1.8	33.0	1.6	249
Other fuel	167.9	4.2	11.9	0.3	11.9	0.3	11.9	0.3	11.9	0.4	11.9	0.3	11.9	0.6	
Infrastructure and machinery	461.7	11.5	461.7	11.2	461.7	10.7	461.7	12.2	461.7	15.9	461.7	12.6	461.7	21.7	450
Total	4009.4		4130.9		4320.6		3787.2		2901.2		3661.3		2128.8		3925

[a] Gypsum - assumed to have same emission factor as lime (Wells 2001).

Table 4.24 Contribution of agronomic operations to greenhouse gas emissions (kg CO_2-e/ha) for processing potato, onion and broccoli (Scenario 2).

	Tas 1		Tas 2		Tas 3		Mallee		Lockyer Valley		Onion (Tasmania)		Broccoli (Tasmania)	
	kg CO_2-e/ha	(%)	kg CO_2-e/ha	(%)	kg CO_2-e/ha	(%)	kg CO_2-e/ha	(%)	kg CO_2-e/ha	(%)	kg CO_2-e/ha	(%)	kg CO_2-e/ha	(%)
Fertilising	1631.3	40.7	2357.6	57.1	2204.9	51.0	1754.5	46.3	742.4	25.6	1727.1	47.2	444.8	20.9
Planting	147.9	3.7	160.2	3.9	149.5	3.5	160.2	4.2	151.7	5.2	41.8	1.1	343.1	16.1
Cultivation	325.1	8.1	114.4	2.8	114.4	2.6	162.6	4.3	325.1	11.2	243.8	6.7	162.6	7.6
Weed control	147.3	3.7	111.4	2.7	111.4	2.6	78.6	2.1	24.7	0.9	123.3	3.4	102.0	4.8
Disease control	386.9	9.6	51.0	1.2	323.1	7.5	78.8	2.1	153.6	5.3	130.9	3.6	19.8	0.9
Insect control	3.7	0.1	6.5	0.2	6.5	0.2	13.6	0.4	63.8	2.2	29.9	0.8	17.3	0.8
Harvesting	645.9	16.1	645.9	15.6	645.9	14.9	596.3	15.8	412.4	14.2	767.5	21.0	532.7	25.0
Irrigation	247.7	6.2	210.2	5.1	291.4	6.7	469.0	12.4	553.9	19.1	123.4	3.4	33.0	1.6
Infrastructure and machinery	461.7	11.5	461.7	11.2	461.7	10.7	461.7	12.2	461.7	15.9	461.7	12.6	461.7	21.7
Miscellaneous	11.9	0.3	11.9	0.3	11.9	0.3	11.9	0.3	11.87	0.4	11.9	0.3	11.9	0.6
Total	4009.4		4130.9		4320.6		3787.2		2901.2		3661.3		2128.8	

Table 4.25 Estimated annual GHG emissions kg CO_2-e/ha from processing potato allowing for contributions from seed production (Scenario 2).

	Tas 1	Tas 2	Tas 3	Mallee[c]	Lockyer Valley[c]
Seed grading, cutting and cool storage					
G4 (kg CO_2-e)	57.29	-[b]	-[b]	290.97	227.3
G3 (kg CO_2-e)[a]	2.87	90.63	61.54	14.55	11.36
G2 (kg CO_2-e)[a]	0.14	4.53	3.08	0.73	0.57
Processing crop	4009.36	4130.86	4320.60	3787.17	2901.23
G4 (kgCO_2-e)[a]	200.47	(206.54)[b]	(216.03)[b]	189.36	145.06
G3 (kg CO_2-e)[a]	10.02	10.33	10.80	9.47	7.25
G2 (kg CO_2-e)[a]	0.50	0.52	0.54	0.47	0.36
Total (kg CO_2-e/ha)	4280.65	4236.87	4396.55	4292.72	3293.1

[a] Based on an estimated 1/20 th contribution from preceding generations, due to the multiplication of seed tubers between generations. Contributions from G1 were considered insignificant and not included.

[b] Seed crops of Tas 2 and Tas 3 are bulked up over three field generations while other crops are bulked up over four generations. Figure in parentheses was used to calculate the GHG emissions of preceding generations (G2 and G3) but was not used in calculation of the total energy usage.

[c] Assuming similar seed grading, handling and cutting operations as for Tasmania, with adjustment for seed rate (t/ha) and differences in State emission factors for electricity.

Within each State the relative contribution of the potato industry to emissions in the Agriculture, Fish and Forestry sector varied from 0.01 to 2.11% in Queensland and South Australia, respectively (Table 4.27). Allowing for GHG emissions associated with growing, grading, cutting and cool storage of seed, led to a slight increase in total GHG emissions to 175,845 t CO_2-e, or an average of 5.16 t CO_2-e/ha (Table 4.27). This equated to 0.13% of the 136 Mt CO_2-e GHG emissions attributed annually to the Agriculture, Fish and Forestry sector and 0.03% to the national annual GHG emissions of 576 Mt CO_2-e.

Using average yield for each State, potato production in Australia was estimated to release 0.123 t CO_2-e/tonne crop, which varied from 0.088 to 0.191 t CO_2-e/tonne crop in Tasmania and New South Wales respectively, with no account for seed production and handling (Table 4.27). When contribution from seed production and handling was included, potato production was estimated to release an average of 0.143 t CO_2-e/tonne crop, varying from 0.093 to 0.209 t CO_2-e/tonne marketable crop in Tasmania and New South Wales, respectively (Table 4.27).

Comparison with other studies within Australia

Rab et al. (2008) calculated total on-farm emissions of 258,577 t CO_2-e per year for the Australian vegetable industry, with total emissions (pre-farm, on-farm and post-farm) of 1,047,008 t CO_2-e per year. The potato industry within Australia occupies some 30% of the area devoted to vegetable production, which assuming emissions were equal for all vegetable types would equate to some 77,573 t CO_2-e emissions per year on-farm. Our study estimated emissions from the Australian potato industry of 211,497 t CO_2-e per year (Scenario 1) and 150,575 t CO_2-e per year (Scenario 2). This reflects to some extent the inclusion of some pre- and post-farm emissions in our study, in terms of transport of inputs to the farm and transport of the crop to the factory gate. It is also indicative of potato being one of the highest emitters of GHG's in comparison to other field crops (Lillywhite et al. 2007).

Table 4.26 Estimation of contribution of potato production within Australia to GHG emissions based on case studies and methodology of Scenario 1.

	NSW	VIC	QLD	SA	WA	TAS	Total/average for Australia
Area of potato production (ha) [a]	4568.0	8098.0	3498.0	9403.0	1911.0	6618.0	34096.0
Mean yield in each State (t/ha) [a]	27.0	32.0	25.0	39.0	41.0	46.0	36.0
Annual GHG emissions for the Agriculture, Fish and Forestry sector in each State (Mt CO2-e)[2]	29.1	12.0	69.3	1.8	11.6	2.6	136.0
Emissions not allowing for seed tuber production:							
Estimated Global Warming Potential t CO_2-e	32791.6	61828.9	13362.8	47291.7	9794.0	46427.6	211496.6
Estimated emission of nitrous oxide (t N_2O)	69.6	124.8	27.6	112.5	23.4	118.2	476.1
Estimated emission of nitrous oxide (t CO_2-e)	21581.4	38681.6	8554.1	34871.9	7257.1	36650.3	147596.4
Estimated Global Warming Potential per hectare (t CO_2-e/ha)	7.18	7.64	3.82	5.03	5.13	7.02	6.20
Estimated Global Warming Potential per tonne crop (t CO_2-e/average yield of crop (t))	0.266	0.239	0.153	0.129	0.125	0.153	0.172
Estimated contribution of potato production within each State to emissions for the Agriculture, Fish and Forestry sector (%)	0.11	0.52	0.02	2.63	0.08	1.79	
Emissions allowing for contribution from seed tuber production:							
Estimated Global Warming Potential including seed production (t CO_2-e)	34710.5	65425.2	14746.7	53026.0	10958.4	48464.8	227331.5
Estimated Global Warming Potential per hectare (t CO_2-e/ha)	7.599	8.079	4.216	5.639	5.734	7.323	6.667
Estimated Global Warming Potential per tonne crop (t CO_2-e/average yield of crop (t))	0.281	0.252	0.169	0.145	0.140	0.159	0.185
Estimated contribution of potato production (including allowance for seed production) within each State to emissions for the Agriculture, Fish and Forestry Sector (%)	0.119	0.545	0.021	2.946	0.094	1.864	0.167

[a] Anon 2008a

[b]Total annual emissions of CO_2 equivalents in the agriculture, fish and forestry sector by State (2006) (Anon 2008a).

Table 4.27 Estimation of contribution of potato production within Australia to GHG emissions based on case studies and methodology of Scenario 2.

	NSW	VIC	QLD	SA	WA	TAS	Total/average for Australia
Area of potato production (ha) [a]	4,568	8,098	3,498	9,403	1,911	6,618	34,096
Mean yield in each State (t/ha) [a]	27	32	25	39	41	46	36
Annual GHG emissions for the Agriculture, Fish and Forestry Sector in each State (Mt CO_2-e)[b]	29	12	69	1.3	11.	2.6	136
Emissions not allowing for seed tuber production:							
Estimated Global Warming Potential t CO_2-e	23,551.0	44,233.4	10,148.5	38,037.4	7,725.0	26,880.1	150,575
Estimated Global Warming Potential per hectare (t CO_2-e/ha)	5.16	5.46	2.90	4.05	4.04	4.06	4.42
Estimated Global Warming Potential per tonne crop (t CO_2-e/average yield of crop (t))	0.191	0.171	0.116	0.104	0.099	0.088	0.123
Estimated contribution of potato production within each State to emissions for the Agriculture, Fish and Forestry Sector (%)	0.08	0.37	0.01	2.11	0.07	1.03	0.11
Emissions allowing for contribution from seed tuber production:							
Estimated Global Warming Potential including seed production (t CO_2-e)	25,727	48,536.5	11,519.3	52,959.5	8715.4	28,387.0	175845.0
Estimated Global Warming Potential per hectare (t CO_2-e/ha)	5.63	5.99	3.29	5.63	4.56	4.29	5.16
Estimated Global Warming Potential per tonne crop (t CO_2-e/average yield of crop (t))	0.209	0.187	0.132	0.144	0.111	0.093	0.143
Estimated contribution of potato production within each State to emissions for Agriculture, Fish & Forestry Sector (%)	0.09	0.40	0.02	2.94	0.08	1.09	0.13

[a] Anon 2008a

[b]Total annual emissions of CO_2 equivalents in the agriculture, fish and forestry sector by State (2006) (Anon 2008b).

5. OPPORTUNITIES TO ENHANCE PRODUCTION EFFICIENCIES AND ENVIRONMENTAL PERFORMANCE

5.1 Introduction

The second aim of this study was to analyse the production processes associated with the processing potato industry in Australia and to identify opportunities for efficiency improvements, such as avoiding waste treatments and using fewer resources, while reducing financial costs. Our research and the environmental footprint modelling undertaken in the Section 4 of this report indicates opportunities for enhancing the efficiency of production process, improving overall environmental performance of the industry, and reducing costs. We discuss these opportunities focusing on approaches to sustainable soil management, fertiliser use, water use, fuel use, and carbon sequestration and greenhouse gas emissions. Opportunities for reducing the carbon footprint of the Australian vegetable industry were considered recently by O'Halloran et al. (2008) and are discussed in the context of the environmental footprint focus of our report.

5.2 Soil management

It is considered important to maintain the physical, chemical and biological properties of soil to ensure they are fertile and productive (eg. managing acidity, sodicity, organic carbon, root diseases, fertilisers, water-holding capacity and soil structure) and ensuring that soils are not lost through erosion or are causing off-site effects such as dust, sedimentation or nutrient pollution (Anon. 2001).

Within the vegetable industry in Australia, some of the major soil management issues include soil erosion, soil compaction, and nitrate contamination (Anon. 2001). Erosion control techniques have been developed for use in annual cropping systems on sloping land in parts of Tasmania and other potato growing regions and can be very effective if adequately implemented. For example a mulched rip-line technique has been used to protect hundreds of hectares of land in north-west Tasmania and has been shown to stop soil erosion in autumn and winter-down crops (Tasmanian SoE 2006). Research on farms in north-west Tasmania shows that on steeper cropping land (ie. over 18 degrees slope) significant reduction in yield (8-15%) may occur as a result of water erosion (Cotching et al. 2002). These losses are not apparent on lesser slopes with eroded areas and indicate the need for local management interventions to stabilize soil erosion and enhance crop yield. Processing potato growers are aware of the need for soil conservation and management although the level of adoption of suitable techniques to achieve suitable outcomes vary regionally (eg. TQA 2008).

Studies on river condition indicators in north-west Tasmania provide an indication of the extent of erosion, and its in-stream consequences. Sims and Cotching (2000), for example, found that erosion from intensively cropped catchments in north-west Tasmania can result in off-site environmental degradation such as high stream turbidity and suspended sediment loads. Measurements were made at both catchment and paddock scales with the highest turbidity values recorded in run-off from fallowed paddocks. The ecological linkages between soil conservation, soil productivity and crop production and yield are increasingly clear, and indicate that the adoption of sustainable soil management techniques will help sustain the productive capacity of agricultural land and help growers maintain crop yield (see also TQA 2008).

Land cultivated with potato is often at great risk of erosion through the preparation of the seed bed, the high percentage of bare ground during early stages of crop development and the potential for run-off water to become concentrated in furrows between potato ridges, leading to the development of rills. Risk of erosion is increased with over-irrigation or heavy rainfall, steepness of slope and length of time that the ground is bare (eg. Cotching et al. 2002).

Methods for control of erosion in potato production in the UK (Defra 2005) include i) remove and minimize compaction, ii) leave the soil surface covered with stubble, a cover crop or rough cultivated for as long as possible prior to preparation for planting, iii) avoid stone and clod separation when soil is wet, iv) avoid overworking soil, v) use tied ridges and dikes in furrow bottoms to improve infiltration and reduce run-off, vi) avoid over application of irrigation water to prevent run-off, vii) plant varieties for early harvesting on land at risk of erosion to allow establishment of winter cereal or cover crop, viii) carry out a tined cultivation or rough plough following harvest to minimize erosion on bare rutted surfaces.

A similar situation has been observed overseas in both the UK and New Zealand. For example, the Pukekohe Vegetable Growers Association (PVGA) in New Zealand established the Franklin Sustainability Project in 1997 to identify and endorse best management practice to address sustainability issues such as soil and water conservation in commercial vegetable production. Major soil erosion has been recorded near Pukekohe and a considerable amount of soil was reported to enter streams and the nearby Manukau Harbour and sea. The Franklin Sustainability Project was able to demonstrate that a reduction in soil exposure to surface run-off was essential to reduce soil loss and help maintain agricultural production and yield (Anon. 2001).

Further loss of soil can occur during the harvesting of potato, with estimates in Belgium of 0.2 to 21.4 Mg/ha of soil removed during the harvesting process (Ruysschaert et al. 2006).

5.3 Fertiliser use

Fertiliser use for potato production may impact on the environment, and the fertilisers may directly and indirectly result in GHG emissions implicated in climate change. The nitrous oxide resulting from fertiliser applications on potato crops is a strong GHG with a global warming potential of 310 kg carbon dioxide-equivalents (CO_2-e)/kg N_2O.

There are often opportunities to reduce fertiliser application during potato production, and save on costs. There was a wide range in nutrient application rates between different case studies in our study, even with the same variety in the same geographic area. This would suggest there are opportunities for efficiencies.

There are also opportunities to improve the selection of fertilisers so as to minimise GHG emission. These opportunities include: (i) select fertilisers produced from modern processing techniques, (ii) select fertilisers with lower GHG emissions, (iii) select fertilisers that have been produced with raw materials that have a short transport distance, and (iv) when buying fertiliser, take into consideration not only the GHG emissions per tonne of product, but also give consideration to GHG emissions per tonne of element. Different amounts of base elements (P, N, K etc.) are contained in different fertiliser formulations (O'Halloran 2008). The calculation of GHG emissions on the basis of 'per tonne of element' changes the relative importance of each fertiliser formulation in terms of its emissions (Kongshaug 1998 cited in O'Halloran 2008).

Unfortunately, it may not be straight forward to determine the most appropriate fertilisers to use for different production situations, while aiming to reduce emissions from this source. O'Halloran (2008) has suggested that there is need to review GHG emissions from fertiliser manufacture and fertiliser products used in Australia to provide better guidance to farmers. We would endorse this suggestion.

Approaches to help minimise the environmental impact of fertiliser use on farms were outlined by the Franklin Sustainability Project (Anon. 2001). The Project produced a set of guidelines with suggestions for fertiliser use including (i) improving target rates, (ii) improving placement and timing of the application, and (iii) using cover crops to increase soil protection in winter from run-off.

Other approaches to improving nutrient use efficiency include nutrient calculators. Such calculators have been developed to provide an indication of the appropriate rate of fertiliser application and are considered an important management tool for cropping systems (Biswas et al. 2008). The Central Queensland Sustainable Farming Systems group, for example, has developed a nitrogen fertiliser calculator with an emphasis on climate risk management. Climate risk management in this nitrogen nutrient calculator utilises outputs from the Whoppercropp program and Howvet program (Cox et al. 2003, Nelsen et al. 2002 cited in Cox et al. 2006). The Whoppercropp program is used to provide information on potential yield outcomes. The Howvet program is used to calculate soil water (Cox et al. 2006).

The Potato calculator is another software nutrient calculator developed by Crop and Food Research, New Zealand (Anon. 2007). The Potato Calculator is a simulation model that provides a day by day account of potato crop requirements for nitrogen and water in response to management practices and local weather. Given the requirement of the New Zealand Regional Council for producers to demonstrate compliance regarding a reduction in potato production impacts on the environment, the Potato Calculator has been used to improve the match between fertiliser application and crop requirements (Anon. 2007).

5.4 Water use

The productive capacity of Australian agriculture is threatened by lack of water and climate change. The National Farmers Federation has called on governments to support the adoption of new technologies and agricultural practices that will 'drought proof ' Australian farms (DPIW 2008). Innovative approaches to agriculture are required to achieve the desired new standards of water use efficiency and environmental performance. The agricultural sector in Australia is currently the major industry consumer of water. In 2004-05, it accounted for 65% of all water consumed and Tasmania was ranked as the second highest State with 40.6% of farms irrigated (Anon. 2007). As access to water becomes more expensive and uncertain, new farm management systems are required to improve water use efficiency in irrigation based agriculture.

Potato production requires high water use in comparision to many other crops, and improve strategies are required to enhance water use efficiency in the processing potato industry in Australia. Access to, and efficient use of, suitable quality and quantities of water for production purposes in important as is the need to ensure that local water resources are not adversely affected by operations (eg. insufficient environmental flow or contamination by chemicals, nutrients or sediments).

There are significant opportunities for improved water use efficiency in potato crops. For example, the 2006 grower survey (L. Sparrow and N. Crump pers. comm.) indicated that some 61% of Tasmanian growers utilized big gun traveling irrigators, while only 5% used more efficient centre pivots and linear move irrigators. Furthermore the survey indicated that despite the influx of new and cheaper technologies for soil moisture monitoring over the last 20 years, most growers still relied on visual estimates of soil moisture for irrigation scheduling decisions. This suggested that further grower education was required, or that technologies to monitor soil moisture need to be made cheaper and easier for growers to adopt them.

Better use of irrigation equipment and the deployment of more efficient irrigations systems and irrigation scheduling systems will help conserve water and reduce costs in the short term. In the medium to longer term, the use of new technology in irrigation systems will enable water resources to be managed more efficiently and effectively. The recent development of Wireless Sensor Networks (WSNs) by the CSIRO has the potential to significantly enhance water use efficiency in the Australian agricultural industry. Horticulture Australia is supporting new research based on the sophisticated use of WSNs and precision location technology to support site-specific precision irrigation that will deliver irrigation water efficiently and effectively by applying differential volumes of water on different areas of a cropping field as required. If this research is successful, it should help to reduced water consumption, generate savings as a result of reduced energy and labour costs, increase crop yield and quality, improve disease management, reduce leaching of soil nutrients and enhance environmental performance.

Although controllers and variable rate technology (VRT) are now commercially available for broadacre cropping, adaptation of this technology for application in the vegetable industry has been restricted by the lack of engineering ingenuity of this technology.

5.5 Energy use

Generally, irrigation is the major user of energy on farms regardless of the type of farming operation (eg. cropping, dairy or mixed). Up to 75% of the total farm energy can be attributed to irrigation practices (ABS 2004). In addition, irrigation of summer grown crops within the farm sector has been shown to be a potentially strong emitter of GHG, in particular the nitrous oxide due to fertiliser use (Flessa et al. 2002).

Irrigation energy efficiency strategies outlined by ABS (2004) include:

- ensuring efficient running of equipment
- to improve energy use install new energy efficient equipment systems
- ensure the correct tariff is charged for electricity use on the farm
- maintain current irrigation system to minimise leakage
- ensure the inside of irrigation pipes and fittings are clean and free from scum to reduce friction resulting in increased pumping costs
- ensure correct water application rate is applied to reduce potential run-off
- utilise soil monitoring equipment to ensure correct irrigation scheduling.

In addition, the data of the ABS (2004) suggested that energy consumption during irrigation can be reduced by up to 50% with the addition of a variable speed drive pump and this technology will ensure appropriate pressure and flow requirements are met in the field. Other strategies to reduce water use during irrigation practices include avoiding irrigation in windy conditions (although not always practical) and irrigating at night (if possible) as the tariff is generally cheaper and evaporation loss is reduced (Barber and Pellow 2005).

Alternatives strategies for reducing GHG emissions from diesel use during farm machinery and transport operations include the use of liquid petroleum gas (LPG) and biodiesel. Biswas et al. (2008) highlight this potential strategy to reduce GHG emissions during the production of wheat in Western Australia. In comparison to diesel the CO_2 emissions from biodiesel were 78% less than that to produce equivalent power (Sheehan et al. 1998 cited in Biswas et al. 2008). Although 40% less emissions were reported for pure biodiesel compared to conventional fuel use.

Barber (2004) outlined a number of measures for reducing energy use in vegetable production (Table 5.1). Many of these measures would have both an environmental and financial benefit to growers.

Table 5.1 Some methods of reducing energy usage on farm (adapted from Barber 2004).

ACTIVITY	MANAGEMENT OPPORTUNITY
Land preparation	Reduced tillage
	Driver education and awareness
	Improved matching of tractors and implements to tasks
Irrigation	Efficient pumping
	Efficient water application
	Better soil moisture monitoring and irrigation scheduling
Nutrient application	Reduced applications
	Split applications to match plant demand
	Regular soil and plant analysis
	Biological nitrogen fixation
Pest and disease control	Use of integrated pest management
	Resistant varieties
	Efficient spray equipment and application
Transport	Larger central operations
	Driver education

Barber (2004) also summarised a number of means by which energy could be conserved in the use of tractors and implements. Barber (2004) gave the example of one grower who achieved a 10-15% fuel saving during rotary cultivation simply as a result of changing gear selection and reducing revolutions. Given the rising cost of fuel and the opportunities for significant savings in fuel use it would be timely to promote a tractor driver education campaign in Australia. In terms of fuel use, our study highlighted two case studies (Tas 2 and Tas 3) in which a more efficient one-pass cultivation method was being used. There are opportunities for the rest of the industry to investigate such systems. Similarly controlled traffic systems could offer a number of potential advantages to the vegetable industry, including energy savings, if suitable agronomic techniques and equipment were developed.

5.6 Greenhouse gas emissions

O'Halloran et al. (2008) suggested that the first step in reducing the carbon footprint and GHG emission of the vegetable industry in Australia was to identify the source of the major emissions in the production system and to ascertain if it is economical and practical to alter the system to reduce this identified major GHG emitter. These authors highlighted that there are opportunities to reduce 'upstream' emissions resulting from crop production as well as on-farm emissions through decisions made by growers to use inputs (e.g. fertilisers, electricity, building materials) with low emissions and embodied energy. However, inadequate labelling of products makes it difficult to achieve this in the short term in the absence of increasing regulatory requirements for product labelling (O'Halloran et al. 2008). The Carbon Pollution Reduction Scheme planned for introduction in 2010 by the Australian government should contribute significantly to these ambitions, even though agriculture is not formally involved in at this stage.

On-farm GHG emissions vary between farms depending on, for example, crop production systems, location, input sources and climate. Australian farms will require a system of auditing emissions of GHG at an individual farm level to assess origins of particular GHG emission contributions and to identify mitigation potential for that origin.

5.7 Carbon sequestration

Continuous cropping of soils has been well demonstrated to result in a reduction in soil carbon, with associated reduction in soil 'quality' e.g. physical structure and biology.

This can lead to further environmental problems in terms of soil erosion, the requirement for greater inputs of nutrients and water to maintain yields, and the increased potential for nutrient leaching and eutrophication of waterways. Common methods of maintaining soil carbon include the use of green manures, the use of pasture in the crop rotation and incorporation of stubble from some rotation crops.

Carbon sequestration has become an important issue in Australian agriculture. Recently in Australia several simulation models have been developed to estimate potential additions to cropping soil and emissions. Simulation models developed include: (i) the SOCRATES model (Soil Organic Carbon Reserves and Transformation in agro-Ecological Systems) developed by the CRC for Soil and Land Management (CSIRO, Adelaide), and (ii) the Grains Environment Data tool (GEDT) and a spreadsheet developed through the National Greenhouse Gas Initiative - a joint venture between CSIRO, University of Melbourne, GRDC, Victorian DPI, and Department of Agriculture and Food Western Australia. Carbon sequestration of up to 0.01% of organic carbon per year (~100kg/ha per annum) has been estimated using SOCRATES with typical Australian cropping areas, crop inputs and rotations (GCA 2007).

Another carbon emissions model, the C-Lock system was developed in the USA and implemented in South Dakota to provide a method of certifying and quantifying carbon emissions reduction credits (CERC) at a project-level. The system enables landowners to trade CERCs occurring from management practices generated in agriculture. The C-Lock system consists of four major components and includes a GIS-linked database providing land-use, climate and soil data, a 'CENTURY' soil organic matter model (Parton et al. 1993 cited in Zimmerman et al. 2005), and a web-based user interface client database (Zimmerman et al. 2005). Zimmerman et al. (2005) used this system to asses the effect of three management scenarios (reduced tillage, no tillage and conventional tillage) in corn (maize)/wheat/soybean rotation on soil C stocks. Estimated soil organic carbon accumulation in the representative field between 1990-2030 was highest for conservation tillage scenario (reduced tillage but same crop rotation) (0.51 Mg C/ha/yr) followed by no tillage (0.36 Mg C/ha/yr), then reduced tillage (0.10 Mg C/ha/yr), and lastly by conventional tillage (0.08 Mg C/ha/yr), and highlights the advantage of adopting reduced tillage.

5.8 Conclusions

In this Section we examined the production processes associated with the processing potato industry in Australia and suggested a number of opportunities for efficiency improvements. It is evident that potato growers can improve their environmental performance by recognising environmental issues and continuing to make refinements to their existing management approaches, or by using new approaches to production. The importance of the sustainable management of natural resources such as soil, water and land is widely recognised and continues to receive high priority for funding under existing and new government policy initiatives in Australia. This means that the processing potato industry is well-placed to partner with governments, catchment management authorities and other resource managers to enhance its environmental performance. Similarly, with the support of Horticulture Australia, the industry is well placed to be pro-active and address the pre-eminent global concern of climate change. To do this, the industry will need to better understand its net greenhouse gas emissions or carbon footprint and invest in new initiatives to facilitate credible mitigation and adaptation responses to climate change. We discuss how this might be done, strategically, in Section 6.

6. GENERAL DISCUSSION AND RECOMMENDATIONS

6.1 Introduction

In this study we have examined the production processes associated with the processing potato industry in Australia and suggested a number of opportunities for efficiency improvements, such as avoiding waste treatments and using fewer resources, while reducing financial costs. The adoption of refinements to existing management approaches and the uptake of new management approaches – especially in the areas of soil management, fertiliser use, water use, fuel use, carbon sequestration and greenhouse gas emissions - will improve the environmental performance of the industry and allow gains in efficiency and productivity.

Below, we summarise our research to quantify the environmental footprint of the processing potato industry in Australia, and compare the environmental performance of the industry to other horticultural industries. We then outline a series of recommendations that should allow the industry to be proactive in tackling its environmental issues and advancing its reputation as a committed environmental steward.

6.2 Environmental performance of the processing potato industry

Our research has shown that the processing potato industry can have a significant impact on soil, water and land resources. Soil conservation and sustainable land management are important challenges for the industry in all areas where potatoes are grown. Water conservation and the adoption of water use efficiency technologies is a priority for the industry and will help to reduce energy use and the costs of production.

The main emitters of greenhouse gases in potato growing were fertiliser (24.9-55.9% of emissions), diesel use (25.9-39.5%), agrichemical use (3.5-8.9%), infrastructure (10.7-15.9%) and electricity (0-19.1%) (based on Scenario 2, Section 4). This was similar to potato production in New Zealand where Barber (2004) reported the emissions as 38.9%

for fertiliser, 30.6% for diesel, 12.7% for agri-chemicals, 11.5% for infrastructure and 6.3% for electricity (6.3%).

On farm production of potatoes may produce in the order of 2.5% of the emissions of CO_2-e from the Agriculture, Forestry and Fisheries sector at a State and Territory level. In comparison to other horticultural industries, the potato industry is likely to be one of the main emitters of greenhouse gases. We believe that the industry needs to be seen by the public and by government to be proactive in reducing GHG emissions. Some methods to reduce GHG emissions will also have the added advantage of reducing the costs of production to growers and processors.

6.3 Sustainability and industry innovation

Major companies involved in the vegetable industry globally are embracing sustainability as a means of reducing costs, and providing an improved marketing image. A number of major companies in the industrial sector have announced ambitious plans to introduce more sustainable and cost-effective production practices through measures such as reducing energy consumption and the recycling of waste.

The Unilever company has been used to illustrate innovations in the use of sustainability to maintain market advantage (Pretty et al. 2007). In 1997, Unilever embarked on an internal process of adopting agricultural sustainability principles for its various food businesses, including peas, black tea, spinach, tomatoes and palm oil (Pretty et al. 2007). Unilever adopted its own indicators of sustainability including a) soil fertility and health, b) soil loss, c) nutrients, d) pest management, e) biodiversity, f) value chain, g) energy, h) water, i) social and human capital, j) local economy and k) animal welfare. The company supported the Colworth experimental farm in the USA, comprising some 500 ha, which was used to assess and demonstrate new agricultural methods and practices in a commercial situation, but with no commercial pressures (Pretty et al. 2007).

Another example of using sustainability and environmental performance to competitive advantage is the HJ Heinz Company which had total sales of some US $9 billion in the 2007 fiscal year (Heinz 2007). The company is committed to a range of socially responsible programs around the world and has a major interest in implementing energy savings in an effort to mitigate the impacts of rising energy costs and reduce GHG emissions (Heinz 2007). Globally, Heinz GHG emissions totalled some 900 metric tonnes of CO2-e in 2007 (Heinz 2007). For its North America operations, the Heinz company anticipated saving 19.5 M Kwh of electricity and 54 billion BTU's of natural gas in 2008. It is estimated that some 3 million cubic metres of water have been saved as a result of innovations in global manufacturing operations, including a 50% reduction in water used per tonne of product manufactured at their Echuca facility in Australia (Heinz 2007).

Recently, the major potato chip producer 'Frito-Lay' announced plans to produce an 'environmentally-neutral' potato chip in the USA (Martin 2007). The Frito-Lay factory in Casa Grande, Arizona processes 230,000 kg of potato each day, and makes 212 million bags of chips per year. The factory is a major consumer of energy, with natural gas consumption in a year sufficient to heat 13,000 homes. In a bid to establish 'green credentials' to consumers and perhaps derive a marketing advantage, Frito-Lay is embarking on a policy of 'net zero' which will see the factory run on renewable fuels and recycled water. By 2010, the company aims to reduce electricity and water consumption by 90%, reduce the use of natural gas by 80% and reduce GHG emissions by 50-75%. Should the plan be successful, it will be adopted at 37 other Frito-Lay plants in USA and Canada (Martin 2007). While this endeavour apparently seeks to encompass only the processing end of the supply chain, it signals that at least one major player in the potato industry is taking the issue of sustainability very seriously.

Changes in transport of Tokachi potato in Japan by a number of different companies, has led to a reduction in CO_2 emissions. Nippon Express Co., Japan Freight Railway and Shihoro Agriculture Cooperative Association were 2007 winners of the Director-General for Policy Planning award that recognised the efforts by these organisations to reduce global warming in Japan. The energy-saving by these organisations was demonstrated by a shift of transport of Tokachi potato from road to rail, with a 53% reduction in CO_2 emissions (http://www.japanfs.org/db/2055-e).

6.4 Quantifying the carbon footprint of the vegetable industry

It is important to better understand the overall contribution of the vegetable industry in Australia to global warming and climate change, and the specific contributions of individual industries such as the processing potato industry. In this regard, our study provides important new data on the Australian processing potato industry (from farm to 'factory gate') and demonstrates an approach that could be employed more widely to examine the vegetable industry as a whole.

Prior to the implementation of any major response to climate change by the horticultural industry, we believe that it is important to rigorously test and evaluate techniques using the best available science. A workshop entitled "Vegetable Industry Carbon Footprinting Scoping Study Workshop" was recently held by Horticulture Australia in Sydney. The workshop was attended by representatives of the Australian vegetable industry sector to plan the next phase of R, D & E to address the need to mitigate current emissions in the industry and provide guidance as to how best the industry might adapt to climate change. The published outcomes of this workshop are forthcoming, and we anticipate that our current research will contribute to the development and evaluation of an overall strategy by the vegetable industry to climate change.

6.5 Recommendations of the report

Our research on the environmental footprint of the processing potato industry in Australia has identified a range of opportunities for the industry to enhance its production efficiency and environmental performance. A number of the major opportunities are outlined below. By recognizing and adopting suitable changes to production we believe that the industry will enhance its environmental performance, save costs and increase its competitive advantage in different domestic and international markets.

The industry has an opportunity to pro-actively address its GHG emissions and, in doing so, will be at an advantage as public policies change to facilitate a broader approach to climate change mitigation across the Australian economy.

- **Greenhouse gas emissions**

This study has estimated the potato industry in Australia to produce between 0.02 – 2.6% (Scenario 1) or 0.01 – 2.1% (Scenario 2) of individual State emissions of CO_2-e from the Agriculture, Forestry and Fisheries sector on farm. The on-farm component of potato production is a relatively minor contributor to Australia's GHG emissions. However, in comparison to other horticultural industries, the potato industry is likely to be one of the main emitters of GHG's, due to the high level of inputs (e.g. fertiliser) and relatively large area of land used to grow potatoes. We believe that the industry needs to be seen by the public and by government to be proactive in reducing GHG emissions. Some methods to reduce GHG emissions may also have the added advantage of reducing costs of production.

The industry needs to better understand its relative contribution to GHG emissions, and should gather actual site-specific information with regard to N_2O emissions in different regions and soil types, and from the use of different fertilisers and fertiliser use practices, to more accurately determine GHG emissions for differing production strategies. It is vital for the industry to be prepared for the Carbon Pollution Reduction Scheme (CPRS) and opportunities for carbon trading, should it be included when agriculture enters the CPRS in 2015 or later. Nevertheless, the industry will incur carbon costs through fuel, fertiliser and chemical and other input costs from 1 January 2010, and needs to develop strategies and practices to accommodate and respond to cost impositions from that date. This will mean developing and adopting practices that reduce GHG emissions, and this will be facilitated by modelling GHG emissions for a diversity of locations and production systems across Australia.

In terms of Scenario 2, the main emitters of GHG were fertiliser (24.9-55.9% of emissions), diesel use (25.9-39.5%), agrichemical use (3.5-8.9%), infrastructure (10.7-15.9%) and electricity (0-19.1%). This was similar to potato production in NZ with fertiliser (38.9%), diesel (30.6%), agrichemical (12.7%), infrastructure (11.5%) and electricity (6.3%) (Barber 2004).

O'Halloran et al. (2008) recently summarised a number of ways of mitigating greenhouse gas emissions in the Australian Vegetable Industry. In terms of on-farm emissions, the main methods were under the areas identified above, including irrigation, nitrogen fertiliser use, fuel type and efficiency, tillage, cool storage and packaging. Our study supports many of the recommendations of O'Halloran et al. (2008).

- **Energy use**

The adoption of methods to reduce energy are likely to both reduce GHG emissions and be of financial benefit to growers and the processing potato industry in Australia. In our study, diesel made up a significant proportion of energy use on-farm. There are opportunities for reduced diesel use in the industry. Two of the case studies (Tas 2 and Tas 3 employed a one-pass cultivation system which reduced diesel use. Other opportunities to reduce energy use include the development of controlled-traffic systems, and it is notable that the Australian Potato Research Program 2 is currently calling for a project proposal in this area.

There is an opportunity to develop and implement an education campaign for growers, and the industry more widely, on fuel efficiency in agronomic operations. Investigating the use of alternative fuels (e.g. biodiesel) has merit.

One of the main contributors to electricity use in the growing of potatoes is the pumping of irrigation water. Efficiencies in water use will translate into energy efficiency. From a GHG perspective, the reduction in electricity use is more important in States such as Victoria and Queensland where electricity generation is predominately through the burning of coal.

Nitrogen fertiliser represents a major energy input, and improvement in nitrogen use efficiency will contribute to reduced energy consumption by the industry, as well as contribute to reduced GHG emissions, particularly through lower N_2O emissions

- **Nutrient management**

Improved efficiency of nutrient use will have both environmental and financial benefits to growers. New R, D & E is required to improve the efficiency of nutrient use on farms. Ways to improve efficiency include the demonstration of decision support tools such as the Potato Calculator to better match nutrient application, particularly of nitrogen, with crop demand, the identification and use of fertilisers with lower capacity to contribute to N_2O emissions or leaching and run-off, and the promotion of methods of managing nutrients left over in crop residues and soil after crop harvest. Whole system research is indicated, with particular emphasis on aspects that enhance nutrient use efficiency and recovery through the crop rotation cycle, as distinct from within single crops.

- **Water use efficiency**

Growers will face increasing pressure to improve water use efficiency across Australia. There are opportunities for more efficient use of water through the adoption of more efficient irrigation systems and irrigation scheduling techniques, and perhaps through the use of potato varieties that require less water (as in Tas 2). While technology to increase water use efficiency is continually improving, uptake is often hampered in that irrigation infrastructure is costly. With the trend towards fewer and larger vegetable farms in the industry, there is also a move towards new and improved infrastructure due to improved economies of scale. It is likely that the industry will continue to update to more efficient irrigation infrastructure. Growers can be assisted through providing them with information on the benefits of particular irrigation systems and through training in the use of irrigation scheduling tools and the development of cheaper and more user friendly technologies. Research into precision irrigation in the vegetable industry is currently being undertaken within Australia and clearly has an important role to play in water conservation, and enhancing water savings and associated cost savings to growers.

- **Soil management**

Soil management is critical to the sustainability of the potato industry. Conventional production practices can lead to significant structural degradation, loss of soil carbon and soil erosion with consequent off-site nutrient contamination. There is a need for the industry to continue to improve soil management practices and to investigate new practices (e.g. controlled traffic). The industry would also benefit from a better understanding of the dynamics of soil carbon and most efficient methods of maintaining or increasing soil carbon.

- **Pesticide use**

Although pesticides appear to represent a relatively minor component of GHG emissions, there are opportunities to reduce pesticide use in the industry. While the processing industry is dominated by the variety Russet Burbank, there are advantages in utilising more disease resistant varieties (as in Tas 2) that may require less pesticide use. There are opportunities for change while major consumers of processed potato demand a particular variety. If these consumers see environmental benefits by reducing pesticide use, then the choice of potato varieties may be critical in responding to this demand. Reducing agri-chemical use also has the advantage of reducing the EIQ rating.

There are opportunities to reduce agri-chemical use by supporting new research that improves the quality of disease forecasting. Similarly, it is important to maintain a strong biosecurity capability at a national and regional level to help prevent the entry of pathogens and pests into Australia that require increased pesticide applications.

- **Adaptation to climate change**

Adaptation responses to climate change in horticulture will need to take a flexible, risk-based approach that incorporates future uncertainty and provides strategies that will be able to cope with a range of possible local climate changes. Initial efforts in preparing adaptation strategies should focus on equipping primary producers with alternative adaptation options suitable for the range of uncertain future climate changes and the capacity to evaluate and implement these as needed. In the short-term, a common adaptation option will be to enhance and promote existing management strategies for dealing with climate variability. This will automatically track early stages of climate change until longer-term trends become clear.

It would be expected that much new research will focus on modeling agricultural systems and their carbon economy and adaptive agronomy. But larger issues requiring research may emerge, especially if the industry expands into, or partially relocates to new production areas.

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