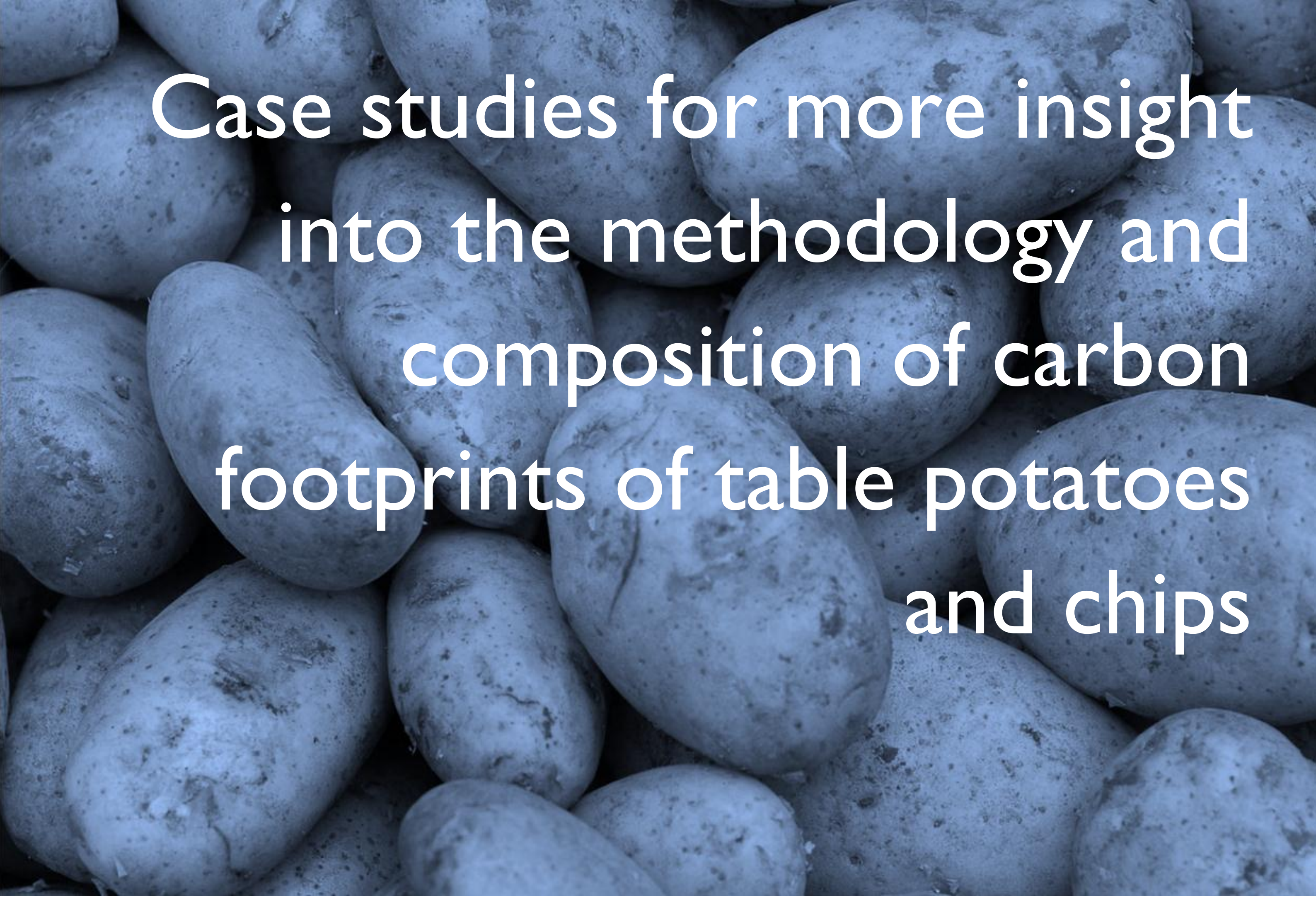

Case studies for more insight into the methodology and composition of carbon footprints of table potatoes and chips

Tommie Ponsioen
& Hans Blonk

July 2011

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giving shape to sustainability

Blonk Environmental Consultants
Kattensingel 3
2801 CA Gouda
Telephone: 0182 579970
Email info@blonkmilieuadvies.nl
Internet www.blonkmilieuadvies.nl

Blonk Environmental Consultants advises companies, government and nongovernmental organizations on putting sustainability into practice. We deliver clear and practical advice based on sound, independent research in an integrated approach that encompasses the whole production chain. Our dedicated staff are committed to the topic, the client, and to delivering practical results.

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Contents

1 Introduction

This report presents the methods and data used to calculate carbon footprints of table potatoes and chips (French fries), the results obtained, and an analysis of the results. The study was carried out by Blonk Environmental Consultants (Blonk Milieu Advies) for the Dutch Commodity Board for Arable Products (Productschap Akkerbouw).

Reason for the study
In September 2009, the governing board of the Commodity Board for Arable Products decided to carry out a study to identify and specify the rules needed for calculating the carbon footprints of processed potato products. This decision was taken in line with the similar steps already taken by the Commodity Board for Horticulture (PT) and the Product Board for Animal Feed (PDV). The aim was to adapt the general rules for carbon footprinting to obtain specifications for arable farming and the processing of arable products, based on two case studies on potato products.

Case study of chips and table potatoes
This report presents the results of the case studies on chips and table potatoes, which were carried out in cooperation with the industry associations and participating companies. The data needed for the analysis were provided by a chip factory and a potato trading company, representing the industry and trade sectors respectively.

Objective
The objective of the study was to determine the most suitable calculation rules for carbon footprinting potato products and processed potato products by preparing carbon footprints for chips and table potatoes. These calculation rules were first derived from the PAS 2050 specification[1] (BSI 2008) and the carbon footprint protocol for Dutch horticultural products based on this specification. In addition, it was examined how the calculation rules set down in the EU Renewable Energy Directive (RED) for biofuels (European Parliament 2009) compare with the calculation rules in PAS 2050.[2]

Structure of the report
Chapter 2 explains the method used. Chapter 3 gives an overview of the data used and the data sources. The results are presented in Chapter 4. Chapter 5 contains the conclusions and recommendations.

[1] PAS 2050 is a publicly available specification of the ISO standards for life-cycle assessment (ISO 14040/44). It was originally prepared for use by British supermarkets (including Sainsbury's, Tesco and Asda), but is much used around the world for calculating carbon footprints.
[2] The case studies do not involve any biofuels and so the RED is, in principle, not relevant, but we do discuss the differences in calculation methods between RED and PAS 2050.

2 Methods

2.1 Standards and specifications

A carbon footprint of a product is the sum of all the greenhouse gas emissions and carbon uptake during the lifecycle of the product that can be allocated to that product. The term ‘carbon footprint of a product’ is a shortened and simplified term for ‘assessment of greenhouse gas emissions during the life cycle of a product’.[3] The ISO standards 14040 and 14044 give general guidance on conducting life cycle assessments, but leave much room for methodological choices, depending on the type of product and the purpose of the assessment. An ISO standard for carbon footprints is currently under preparation (ISO 14067) and is in fact a refinement of the ISO 14040 and 14044 standards for life cycle assessment with respect to greenhouse gas emissions. It is expected that ISO 14067 will be similar to the existing PAS 2050 (BSI, 2008), which – in line with the ISO standards 14040/44 – specifies methodological choices and interpretations for calculating the carbon footprints of products.

PAS 2050 and the draft version of ISO 14067 are both still general in nature and refer to Product Category Rules (PCRs) for a number of methodological choices. These PCRs are product-specific calculation rules drawn up by experts and checked for compliance with the ISO standards. The carbon footprint protocol for Dutch horticultural products[4] is currently being evaluated for partial integration into a revised version of PAS 2050 and possibly for the development of a PCR for horticultural products. The results of this project will be taken on board during the revision of PAS 2050, which is expected to be published in 2011.

PAS 2050 and the PCRs are based on calculations of greenhouse gas emissions according to methodologies set out in the IPCC 2006 Guidelines (IPCC, 2006). The Guidelines define three levels of methodological complexity:

- Tier 1: the basic method (for all categories)
- Tier 2: country-specific methods
- Tier 3: country- and technology-specific methods

The Tier 1 level is the least detailed method and is set down in the Guidelines. The NIRs (National Inventory Reports) contain their own Tier 2 or Tier 3 calculation rules and emission factors based on the IPCC Guidelines. A PCR defines a Tier at the product level, which is often a mixture of methods at the generic, local (climate or soil type) and technology-specific (e.g. fertilization technology) levels. When formulating calculation rules for Dutch agricultural products, Blonk Environmental Consultants draws on the Dutch NIR, which is based on sound research and is representative for the Dutch situation. Moreover, the Dutch NIR does not differ much from the NIRs of other Western European countries. Supplemented by further research, the Dutch NIR could form the basis for the calculation rules and emission factors for arable products in general.

[3] Carbon footprints take account not only of carbon dioxide (CO_2) and methane (CH_4), but also nitrous oxide (N_2O) and other greenhouse gases (e.g. the chlorofluorocarbon coolants). The man-made greenhouse gas emissions consist of 72% CO_2, 18% CH_4, 9% N_2O and 1% other gases. CO_2 emissions are caused mainly by the combustion of fossil fuels, CH_4 primarily by industry and livestock farming and N_2O primarily by crop cultivation and manure production.

[4] See Blonk et al. 2000 for an explanation of the methodology used.

The PAS 2050 and the PCRs are all based on the most recent IPCC 100-year global warming potential (GWP-100) factors for converting the greenhouse gases methane and nitrous oxide to carbon dioxide equivalents.[5] Figure 2.1 is a schematic representation of the guidelines, standards and specifications.

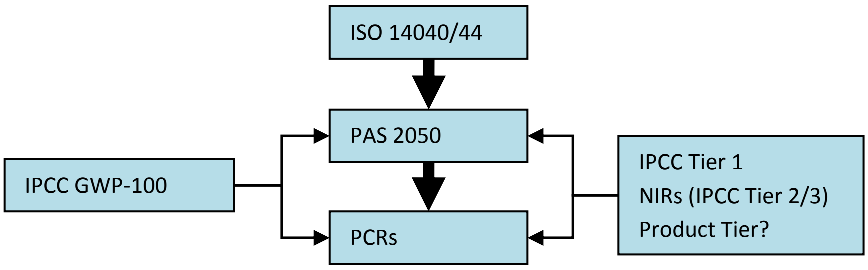

Figure 2.1: Schematic representation of the guidelines, standards and specifications for calculating the carbon footprints of products

2.2 PCR for potato products

PCRs still have to be developed for many product categories. For potato products, one PCR has been approved for chips and is available on the Japanese website www.cfp-japan.jp (Anonymous, 2009). Although this PCR is reasonably comprehensive, no rules are given for allocating nitrous oxide emissions following field-application of manure. This is an important topic for the Dutch situation, because relatively large amounts of manure are used in Dutch potato cultivation.[6] At the moment, use of the Japanese PCR is not mandatory for calculating carbon footprints in the Netherlands.

2.3 System delimitation for the life cycle of chips

System delimitation is the process of determining which stages in the supply chain should be included in the lifecycle assessment. For the calculation of the cradle-to-gate carbon footprints of chips, we included the following stages in the supply chain:

- Manure production
- Cultivation of seed potatoes, ware potatoes and oil seeds
- Processing oil seeds into vegetable oil
- Production of packaging
- Processing of ware potatoes into chips
- Packaging and storage of chips
- Transport between all stages in the supply chain
- Production and use of diesel, natural gas, electricity and fuel oil

[5] The most recent GWP-100 factor for methane is 25 kg CO_2 eq per kg CH_4 and the most recent factor for nitrous oxide is 298 kg CO_2 eq per kg N_2O (see Appendix 1 for previously calculated factors and the differences with GWP-20 and GWP-500 factors).

[6] The Japanese PCR also offers a choice between partitioning the emissions between co-products based on mass (mass allocation) and economic value (economic allocation). PAS 2050, on the other hand, gives no option for mass allocation. The Japanese PCR does not deviate in any other way from PAS 2050 and the carbon footprinting protocol for Dutch horticultural products.

Figure 2.2 is a process diagram showing the links between these processes. Most of the stages in the supply chain included in the calculation of the carbon footprints of table potatoes are the same as those for chips (Figure 2.3).

The cradle-to-gate carbon footprints provide much information about the greenhouse gas emissions in the supply chain that can be allocated to the products. However, this does not complete the picture. A **cradle-to-grave** carbon footprint also includes the user phase (Figure 2.4). In this study, this phase comprises the retail trade, food preparation, consumption and waste processing (including the transport between these stages and the production and use of petrol, diesel, natural gas and electricity). Refrigeration by consumers was not included, because insufficient information was available to allow the use of freezers to be allocated between the different products consumers have in their fridges. The variation of greenhouse gas emissions in the user phase is often many times greater than in the production phase, due to the large differences in transport (bicycle, small car, large car, distance), preparation (cooking method, frying or deep frying) and consumption (food losses) of table potatoes and chips by consumers. A cradle-to-gate analysis is intended for 'business to business' communication. For communication to the consumer, information must also be given on the use and waste phases, for which a cradle-to-grave analysis is appropriate.

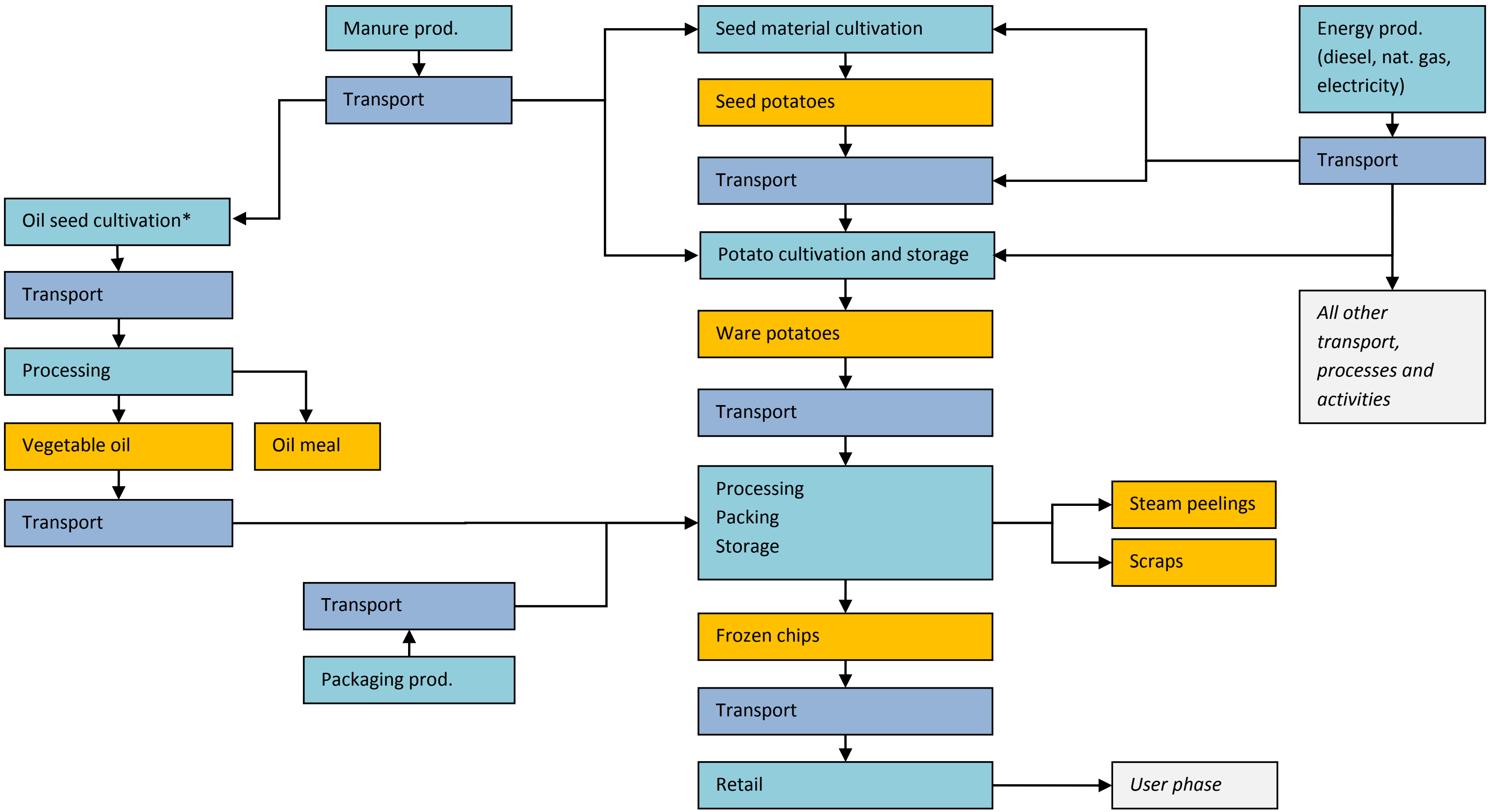

Figure 2.2: Stages in the supply chain included in the life cycle of chips (orange boxes are products; light blue boxes are processes; dark blue boxes are transport)
** oil seeds may be sunflower seeds, oil palm fruits, etc.*

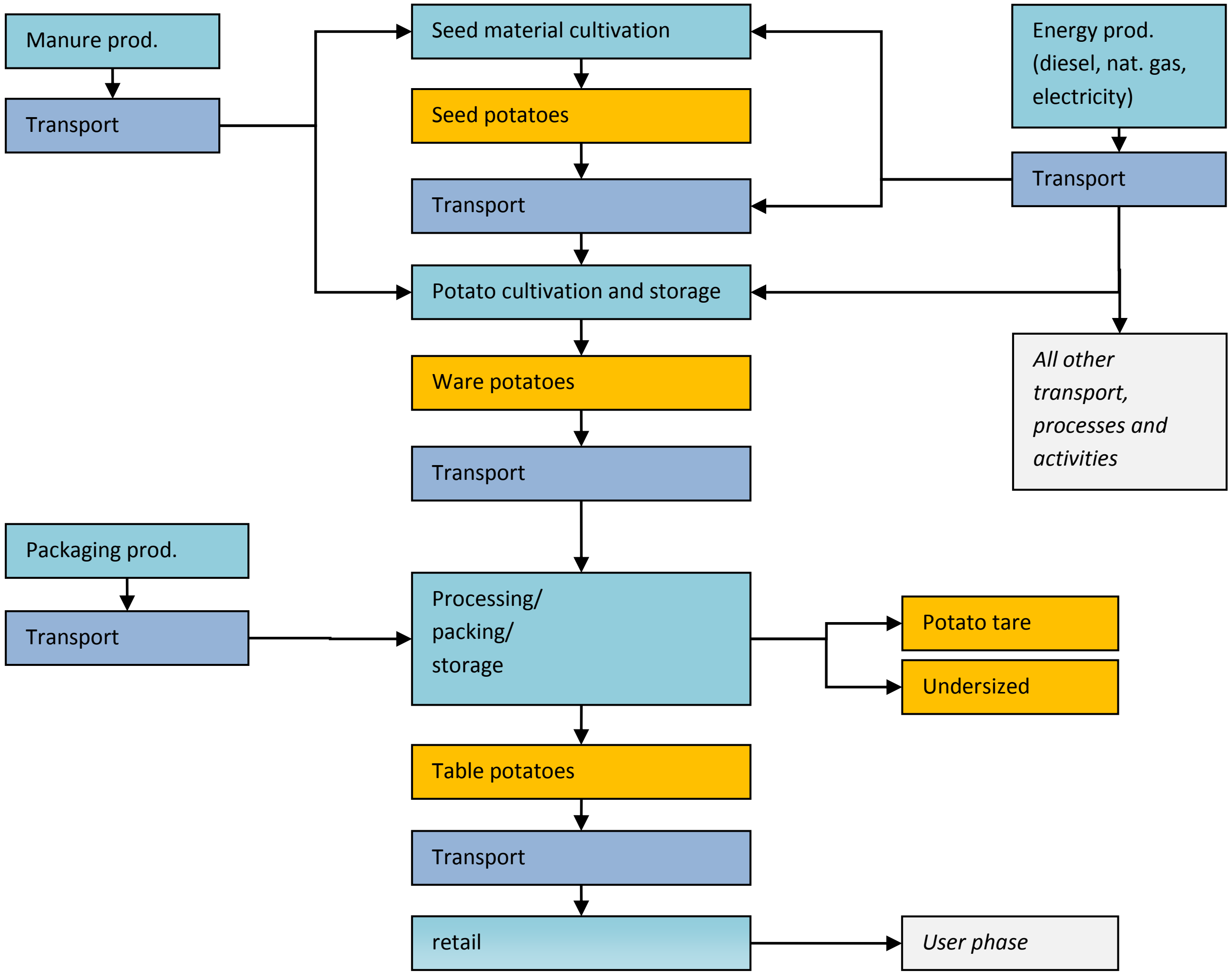

Figure 2.3: Stages in the supply chain included in the life cycle of table potatoes (orange boxes are products; light blue boxes are processes; dark blue boxes are transport)

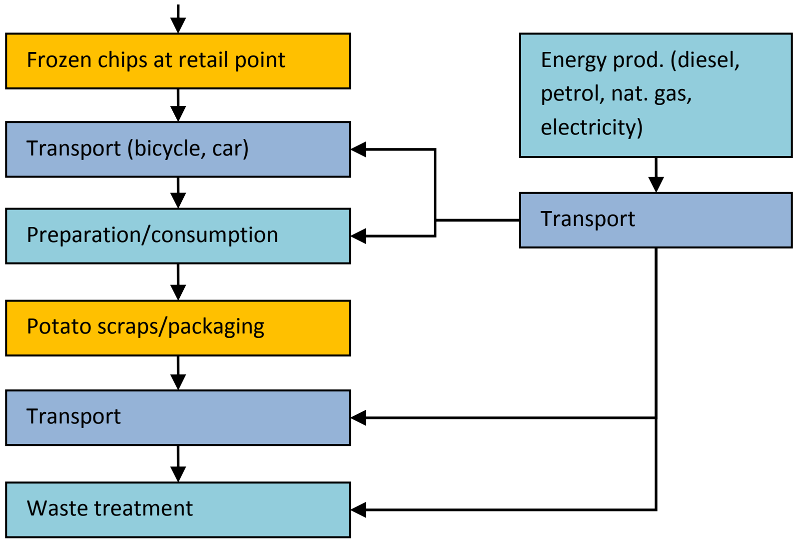

Figure 2.4: Stages in the supply chain included in the user phase in the life cycle of chips (orange boxes are products; light blue boxes are processes; dark blue boxes are transport)

2.4 Emission sources

In principle, all greenhouse gas emissions occurring in each of the stages in the supply chain must be included in the calculation. At the very least, the total greenhouse gas emissions included in the calculation must amount to no less than 95% of the expected carbon footprint totals. If certain sources of greenhouse gas emissions are not included in the calculation, these must be corrected for (e.g., if the sources omitted in a full assessment amount to 3%, the calculated carbon footprint must be divided by 97%).

The activities not included in the supply chains, compared with the Japanese PCR for chips, are:

- the production and transport of tap water and process water;
- the production and transport of chemical pesticides;
- the transport and processing of crop waste and industrial waste.

The assessment reveals that the greenhouse gas emissions from the production and transport of water and chemical pesticides contribute less than one per cent to the carbon footprint of ware potatoes, and that therefore these activities have an insignificant effect on the carbon footprints of table potatoes and chips. The contribution to the total greenhouse gas emissions made by the transport and processing of crop waste and industrial waste is expected to be less than one per cent.

In addition, in line with the PAS 2050 specification, several stages in the supply chain were not included. These are:

- the production chains of capital goods (buildings, tractors, lorries and such like);
- the consumption of food, drinks and goods by employees during working hours;
- transport to and from the normal workplaces of the employees.

We estimate that the calculations in this assessment include almost 100% of the emissions. No correction has been made to compensate for the emissions not included in the calculations. The emission sources included in the calculations and the types of emissions are given in Table 2.1.

Table 2.1: The emission sources included in the calculations and the types of emissions

Source	Type of emission
Chemical fertilizer	Fossil CO_2 emissions and N_2O emissions from the production of chemical fertilizer
Soil	Direct and indirect (via nitrate leaching and ammonia emissions) N_2O soil emissions from nitrogen in chemical fertilizer, manure and crop residues
Diesel/petrol	Fossil CO_2 emissions from the production (oil extraction, transport and refining) and combustion of diesel/petrol for cultivation and transport
Natural gas	Fossil CO_2 emissions from the production (natural gas extraction, transport and refining) and combustion of natural gas for processing
Electricity	Fossil CO_2 emissions from the generation of electricity (production and combustion of fuel oil, coal and natural gas) for cultivation and processing

Emissions from the production of inputs (fossil energy sources and chemical fertilizer) are well documented in the literature. For the potato product supply chains there are no important methodological problems associated with these emissions, although it would be useful to have updated data because the most commonly used emissions data sources date from the 1990s. However, there are a number of important methodological issues for the direct and indirect soil nitrous oxide emissions.

2.5 Direct and indirect nitrous oxide emissions

Parameters for calculating soil nitrous oxide emissions (direct and indirect emission factors, and nitrate leaching and ammonia emissions fractions) are determined at the global level (Tier 1) by the IPCC in its Guidelines for National Greenhouse Gas Inventories. These have been published twice: in 1996 and in 2006. The changes made in the 2006 edition have considerable consequences for the calculation of soil nitrous oxide emissions, but not all the changes are convincingly substantiated. However, the Tier 1 parameter values do not have to be used when drawing up methods for the higher tier levels (Tiers 2 and 3). The NIRs, for example, are a mix of the 2006 Tier 1 method, self-formulated Tier 2 and/or Tier 3 methods, and the 1996 Tier 1 method (implicitly 'promoted' to Tier 2/3).

Table 2.2 lists the various parameters from the IPCC 1996 and 2006 Guidelines and the Dutch NIR 2010. The table shows that the factor for **direct** nitrous oxide emissions from chemical fertilizer, manure and crop residues has been reduced from 0.0125 to 0.01 and that the Dutch NIR 2008 incorporates these changes. The factor for direct nitrous oxide emissions from biological nitrogen fixation (BNF) has been reduced from 0.0125 to 0, but in the NIR it has only been reduced to 0.01. This has no consequences for the emission calculation for potato cultivation, but it is for example significant for pea cultivation. On the other hand, the emission factor in the NIR for direct nitrous oxide emissions following field-application of manure has been set at 0.02, because considerably higher nitrous oxide emissions are expected from the mandatory use of injection techniques for applying slurry. It is also expected that nitrous oxide emissions from ammonium-containing chemical fertilizers will be considerably lower (0.005 kg N_2O-N per kg N). In addition, the direct emission factors are twice as high for organic soils (not shown in the table).

Table 2.2: Parameters for calculating soil nitrous oxide emissions

Parameter	Unit	IPCC 1996 Tier 1	IPCC 2006 Tier 1	NIR NL 2010
Direct nitrous oxide emissions from ammonium-containing chemical fertilizer	kg N_2O-N/kg N	0.0125	0.01	0.005
Direct nitrous oxide emission from other chemical fertilizer	kg N_2O-N/kg N	0.0125	0.01	0.01
Direct nitrous oxide emissions from solid manure	kg N_2O-N/kg N	0.0125	0.01	0.01
Direct nitrous oxide emission from slurry	kg N_2O-N/kg N	0.0125	0.01	**0.02**
Direct nitrous oxide emission from biological nitrogen fixation	kg N_2O-N/kg N	0.0125	**0**	**0.01**
Direct nitrous oxide emissions from crop residues	kg N_2O-N/kg N	0.0125	0.01	0.01
Fraction of ammonia emission from chemical fertilizer (KAS)	kg NH_3-N/kg N	0.1	0.1	**0.02**
Fraction of ammonia emission from manure	kg NH_3-N/kg N	0.2	0.2	**0.1**
Indirect nitrous oxide emission via volatilization of ammonia	kg N_2O-N/kg NH_3	0.01	0.01	0.01
Fraction of nitrate leaching (manure and crop residues)	kg NO_3^--N/kg N	0.3	0.3	0.3
Indirect nitrous oxide emission via nitrate leaching	kg N_2O-N/kg NO_3^--N	0.025	**0.0075**	**0.025**

Only one of the IPCC parameters for **indirect** nitrous oxide emissions has been changed. The parameter for indirect nitrous oxide emission via nitrate leaching has been reduced from 0.025 to 0.0075, but this has not been adopted in the NIR 2010. The ammonia emission fraction for chemical fertilizer and manure is specified in the NIR, and is much lower than in the IPCC Tier 1 method (0.02 compared with 0.10 in the IPCC Guidelines). The emission fraction for manure is also lower (0.10 compared with 0.20). The latter change is related to Dutch legislation, which only permits low-emission manure application.

The calculations used in this study were made using the NIR values, in line with the horticulture protocol. The chosen emission factors may be adjusted slightly after the horticulture protocol has been updated in collaboration with BSI and in conjunction with the revision of PAS 2050.

2.6 Allocation methods for co-production

The processing of potatoes into chips and table potatoes involves co-production, which means that other products are also produced. These can be used as animal feed (steam peelings and scraps). In the chip production chain, co-production occurs in the vegetable oil supply chain (oil and oil meal). The greenhouse gas emissions that occur upstream in the supply chain down to the point where the material flows split (where the co-products leave the factory) must be allocated between the co-products. This can be done in several ways. However, not all allocation methods can be used in each situation, and there are arguments for either using or not using certain allocation methods in a specific situation. In total, there are five allocation methods for carbon footprint analyses (Table 2.3).

Table 2.3: Brief descriptions of the five allocation methods for carbon footprint analyses

	Method	Description
1	Subprocesses	Allocation of greenhouse gas emissions from subprocesses to specific co-products
2	System expansion	Expanding the defined system to include other production systems for products that are equivalent to the co-products and that are not used for the production of the product under study (the carbon footprints of the 'avoided' equivalent products are then subtracted from the greenhouse gas emissions that occur upstream)
3	Mass allocation	Allocation based on the proportions of produced mass
4	Physical allocation	Allocation based on a physical property (protein content, mass density, energy content)
5	Economic allocation	Allocation based on economic value (ex-factory prices)

According to the ISO standards for life-cycle assessments, the possible allocation methods must be evaluated for applicability in the order given in Table 2.3. In the case of vegetable oil, the first option (subprocesses) is not possible because the production and transport of oil seeds cannot be broken down into subprocesses that can be linked to the co-products oil and oil meal. The same applies to the processing of potatoes into chips and table potatoes.

The use of system expansion (option 2) is problematic for potato products and the oils used. There are no fully equivalent products that can be replaced by oil meal without any co-production taking place in the production chains of the equivalent products. One reason for this is the different nutritional values of the oil meals, which means that several types of oil meals are needed as substitutes. These oil meals themselves also have co-products. Further expansion of the system to take account of those co-products would require an enormous amount of data, which would introduce many uncertainties into the study. For steam peelings and scraps, it is equally difficult to find equivalent products that do not come from another co-production process.

Mass allocation is possible if all the uses (food, feed, fuel, fibre) and the properties of the co-products (the qualities required for each use) are the same or practically the same. Mass allocation is therefore not a good option for the production of vegetable oil and oil meal. Oil meal is used mainly as an animal feed and oil is used mainly as a food. Moreover, oil and oil meal have very different nutritional qualities (fat, protein and carbohydrate content). Allocation based on physical properties is also often problematic, because usually no single property can be defined that is a dominant requirement for the relevant use. This is the case when the co-products are used as a fuel, for which the calorific value is a dominant property. None of the processes in the supply chains of chips and table potatoes where co-production occurs are suitable for mass or physical allocation because of the different uses of the co-products.[7]

The calculation rules in the Renewable Energy Directive assume emissions are allocated between co-products according to their calorific values. Besides the conceptual problem of applying energy allocation when not all the co-products are used as a fuel (the calorific value is a property that is only relevant for fuels), energy allocation can also lead to odd results. For example, table potatoes have a very low calorific value because of their high water content (water has a negative calorific value).

Economic allocation
Economic allocation matches the commercial ethos of the company that produces the product: the more that can be earned from a co-product, the more emissions will be allocated to it, and vice versa. The fraction of greenhouse gas emissions allocated to the product under study (in this example, vegetable oil) is then calculated as follows:

$$f_{oil} = \frac{p_{oil} \times m_{oil}}{p_{oil} \times m_{oil} + p_{oil\ meal} \times m_{oil\ meal}}$$

where p is the price and m is the produced mass. The allocation fractions for chips and table potatoes are calculated in the same way.

Economic allocation may give rise to a number of operational difficulties. For example, the market for certain co-products may not always be a free market, because the co-products may be sold on internally to

[7] There are actually few situations in which mass allocation or physical allocation are relevant. These methods are (probably) not included in PAS 2050 for this reason.

companies within a concern or group for upgrading (e.g. slaughter by-products). For oil, chips and table potatoes this is not a problem. However, the ex-factory prices are often not publicly available. Trade prices are often available, but these include transport, which can lead to differences in allocation fractions between ex-factory prices and trade prices. Finally, price fluctuations may lead to large variations in outcome from year to year. This effect can be practically eliminated by using five-year averages.

2.7 Allocation methods for manure

Allocation between crop cultivation and livestock farming
Nitrous oxide is released when manure is applied to fields. The question is whether these emissions should be allocated entirely to crop growing or whether part of the emissions should be allocated to the livestock farm where the manure is produced. This is because crops take up nitrogen from manure less efficiently than from chemical fertilizer. Arable farmers are not concerned about this lower efficiency of nitrogen uptake, because using manure saves on the use of chemical fertilizer and also provides a service (waste disposal) to the livestock farmer. The allocation can be based on the working coefficient, which reflects the difference in uptake efficiency between manure and chemical fertilizer. For example, if the working coefficient is 60% (pig slurry), then 60% of the nitrous oxide emissions from manure must be allocated to crop cultivation and 40% to livestock production. From the research carried out for the Commodity Board for Horticulture, our recommendation is to partition the nitrous oxide emissions from the field-application of manure between crop cultivation and livestock production according to this ratio. This method is included in the protocol for calculating the carbon footprints of Dutch horticultural products and will probably be incorporated into the carbon footprint tool of the Product Board for Animal Feed. In this report we also calculate the difference in the results obtained when all the emissions are allocated to crop cultivation.

Allocation within crop rotations
There is also the question of whether the nitrous oxide emissions (allocated to crop cultivation) should be allocated entirely to the crop for which the manure is applied or whether part of the emissions should be allocated to the crop grown on the same land the following year. This is because some of the nitrogen in the manure will only become available for uptake in the year after it is applied. According to the Nutrient Management Institute (NMI) this proportion is 17% for pig slurry (30 of 180 kg N/ha). This fraction can therefore be allocated to the subsequent crops in a crop rotation. One way of doing this is to partition these emissions between the crops in the cropping plan according to the relative crop areas. Bos et al. (2007) give an example of a cropping plan for seed and ware potatoes on a clay soil with manure application. However, the figures are based on the application of manure in the autumn, with a working coefficient of 30%, but since 2009 this is no longer permitted. The manure now has to be applied in the spring, for which the working coefficient is 60% (pig slurry). It was assumed that in the new situation half the amount of manure is applied. Table 2.4 shows the figures, based on Bos et al. (2007), for calculating the effect of the cropping plan allocation on the total active nitrogen (nitrogen from chemical fertilizer and manure, corrected using the working coefficient).

The total active nitrogen in the cultivation of seed and ware potatoes declines by 7% and 4% respectively if the proportion of the nitrogen that becomes available from the second year is divided over the cropping plan (Table 2.4). However, if the nitrogen from the crop residues is divided over the cropping plan, the effect is much greater. For ware potatoes this means that besides a reduction of 10 kg in active nitrogen from manure, there is also an increase of 37 kg nitrogen per hectare (according to data from Bos et al. 2007; Table 2.5). It should be noted, though, that the last figure depends on uncertain estimates of nitrogen from crop residues and the crops in the cropping plan. It all depends on how representative the example cropping plan is. If, for example, peas are taken out of the cropping plan, the difference would be just 16 kg N per hectare. In this case, the difference in the carbon footprint of potatoes with and without a cropping plan allocation would be very small.

Table 2.4: Cropping plan fertilization and allocation of nitrogen from manure (pig slurry) over the cropping plan (17% of the nitrogen becomes available only in the second year)

	Manure kg N/ha	Manure (allocated) (kg N/ha)	Chemical fertilizer (kg N/ha)	Total active N (kg N/ha)	Total active N (allocated) (kg N/ha)	Difference in total active N (%)
Seed potatoes	105	89	73	136	126	-7%
Ware potatoes	105	89	203	266	256	-4%
Sugar beet	70	61	115	157	152	-3%
Spring-sown onions	105	89	58	121	111	-8%
Winter carrots	0	1	70	70	71	1%
Winter wheat	0	1	205	205	206	0%
Peas	105	89	108	171	161	-6%

Table 2.5: Cropping plan area, nitrogen in crop residues and allocation over the cropping plan

	Area (ha)	Crop residues (kg N/ha)	Crop residues (allocated) (kg N/ha)	Difference (kg N/ha)
Seed potatoes	6.25	80	77	-3
Ware potatoes	6.25	40	77	37
Sugar beet	12.5	117	77	-40
Spring-sown onions	6.25	14	77	63
Winter carrots	6.25	77	77	0
Winter wheat	6.25	3	77	74
Peas	6.25	167	77	-90

2.8 Biogenic carbon (short cycle)

Biogenic carbon is carbon in biomass, which includes all living and dead products that are part of the biosphere, thus excluding peat, fossil fuels and materials. There is complete agreement that the oxidation of biomass within a reasonable period (certainly within a period of 10 years) will lead to a 'zero emission', which means that the CO_2 emissions from oxidation are equal to the earlier uptake of CO_2 from the atmosphere and sequestration in biomass. When drawing up carbon footprints, therefore, the CO_2 emissions of biogenic carbon are often left out of the calculation. The current position in the development of the current ISO 14067 standard is that both biogenic and fossil carbon should be included in the inventory. No explicit recommendations are given about the presentation of the carbon footprint. In this case study we show what a separate presentation could look like.

2.9 Land use and land use change (LULUC)

The project for the Product Board for Animal Feed concluded that the carbon footprint emissions from land use and land use change (LULUC) can be relevant and should therefore be calculated, but that the results should be presented separately because of the uncertainties inherent in such calculations. In this project we also calculated the LULUC emissions and examined how they could be presented in combination with the presentation of biogenic carbon.

3 Data

For the calculation of the carbon footprint of table potatoes we used data on the cultivation of seed potatoes and ware potatoes, transport, storage and processing obtained from a potato growers' association. For the calculation of the carbon footprint of chips we used cultivation data from KWIN (Schreuder et al., 2009) and data on transport and processing into chips from reliable sources in the open literature. Data on the greenhouse gas emissions from the production and use of inputs were obtained from the database held by Blonk Environmental Consultants, which is based on recent and reliable literature sources. For the user phase we collected data from the literature.

3.1 Cultivation data

The cultivation data used are shown in Table 3.1. The input and output figures for seed potatoes and ware potatoes for table use are from Bos et al. (2007). For ware potatoes for making chips we assumed that there are no differences in inputs between potatoes for chips and table potatoes, despite the fact that the yields of chip potatoes are 30% higher than those of table potatoes. According to KWIN (Schreuder et al., 2009), chip potato yields are 60 tonnes per hectare. We assumed that supplies of ware potatoes amount to 95% of the field yield. The figures for average electricity consumption for potato storage at the grower were obtained from a potato trading company.

Table 3.1: Cultivation data

Input or output	Unit	Seed potatoes	Ware potatoes (table)	Ware potatoes (chips)
Nitrogen in chemical fertilizer	kg/ha	0	150	150
Nitrogen in organic fertilizer	kg/ha	120	150	150
Potash in chemical fertilizer	kg/ha	170	125	210
Phosphate in chemical fertilizer	kg/ha	0	75	120
Tractor fuel	kg/ha	110	130	240
Nitrogen in crop residues*	kg/ha	80	40	40
Seed material	tonne/ha	5.2*	3,0	3.0
Field yield	tonne/ha	40	54	60
Delivered yield	tonne/ha	40	52	57
Electricity for storage	kWh/tonne	32	52	52

** Nitrogen in crop residues is not an input, but in the calculation of nitrous oxide emissions via the soil it is treated as an input (source: Bos et al. 2007)*

3.2 Transport and processing data for table potatoes

The data used that are specific for the table potato production chain are given in Table 3.2 (transport), Table 3.3 (processing) and Table 3.4 (allocation).

Table 3.2: Transport data

Parameter	Unit	Seed material to grower	Grower to processor	Processing, distribution centres, shops
Transport distance	km	50	50	125
Capacity	tonne/vehicle	40	40	28
Load	tonne/vehicle	25	25	18

Table 3.3: Processing data

Parameter	Unit	Amount
Natural gas	m3/tonne	0.6
Electricity	kWh/tonne	6.0
Packaging material	kg/tonne	5.0
Reject fraction	tonne/tonne	0.19

Table 3.4: Allocation factors

Co-product	Relative mass of production (kg/tonne)	Relative economic value (€/€)	Economic allocation fraction (-)	Mass allocation fraction (-)
Packed potatoes	810	1	0.94	0.85
Soil	51	0	-	-
Potato dirt tare	65	0.3	0.02	0.07
Undersize	74	0.5	0.04	0.08

3.3 Processing data for chips

Based on the data from Bruinsma and Oldenhof (2006), gas consumption was estimated at 70 m^3 per tonne and electricity consumption at 120 kWh per tonne of potatoes (Table 3.5). This corresponds to about 5 MJ primary per kg chips for energy intensive processes such as steam peeling, blanching, frying and cooling, and about 2 MJ primary per kg for freezing chips. It was assumed that natural gas is used for energy-intensive processes and electricity is used for freezing, and that the amount of packaging material is about the same order of magnitude as that used for table potatoes. We estimated that the amount of vegetable oil used is 25 kg per tonne potatoes (frozen chips contain about 5% fat from vegetable oil) and that a tonne of potatoes produces about 500 kg chips (according to Janssens et al. 2006). The amount of electricity used for cooling in the shop (200 kWh per tonne chips, or 2 MJ primary per kg) is based on Bruinsma and Oldenhof (2006).

Table 3.5: Inputs for the processing of ware potatoes into frozen chips (based on Bruinsma and Oldenhof 2006)

Input	Unit	Amount
Natural gas	m^3/tonne potatoes	70
Electricity	kWh/tonne potatoes	120
Packaging material	kg/tonne potatoes	5
Vegetable oil	kg/tonne potatoes	25
Cooling in the shop	kWh/tonne potatoes	200

Table 3.6 shows the outputs and allocation factors for processing ware potatoes into frozen chips. The prices are estimates based on Janssens et al. (2006) and the website Boerderij.nl. Because the difference in price between chips and the by-products is so great, a halving or doubling of one of the prices makes no significant difference to the carbon footprint of chips. However, it does have a big effect on the carbon footprints of the by-products. The figures can therefore be used to calculate the carbon footprint of chips, but not for any of the by-products.

Table 3.6 Outputs and allocation factors for the processing of ware potatoes into frozen chips (based on Janssens et al 2006 and the website Boerderij.nl).

Output	Amount (kg/tonne)	Price (€/tonne)	Economic allocation factor
Frozen chips	465	500	0.98
Steam peelings	140	20	0.01
Potato scraps	47	30	0.01

3.4 User phase

The data used for calculating the contribution made by table potatoes and chips in the user phase to the cradle-to-grave carbon footprint are based on estimates, assumptions and information from the literature (Table 3.7).

1. Transport (petrol use), storage (freezer) and the cooking, frying and oven use fractions are based on estimates.
2. For cooking, we assumed that 63 m^3 natural gas are used in a total of 385 hours of natural gas consumption per household (Milieucentraal 2010); this is 0.054 m^3 per kg (20 minutes).
3. For frying, we assumed that the gas ring is turned on twice as high.
4. We assumed the power output of the oven is 2000 Watts; this gives 2000 Watt * 60 seconds * 10 minutes (mainly pre-heating) = 0.33 kWh per kg.
5. For deep frying, we assumed a power output of 2000 Watts; this gives 2000 Watts * 60 seconds * 10 minutes (mainly pre-heating) * 2 (a half kilo of chips in each batch) = 0.67 kWh per kg.
6. We assumed that 250 grams of sunflower oil is used per kg chips (1.5 litres of oil for 6 kg chips).
7. A dishwasher uses about 300 kWh per year, or 1.4 kWh per cycle (NUON 2010). We assumed that 20% of the load in each dishwasher cycle consists of the cooking utensils and tableware used for the consumption of one kilogram of potatoes.

Table 3.7: Data used for calculating the contribution by table potatoes and chips in the user phase to the cradle-to-grave carbon footprint

	Petrol (kg/kg)	Natural gas (m^3/kg)	Electricity (kWh/kg)	Fraction (kg/kg)
Transport[1]	0.01			
Storage[1]			0.01	
Cooking[2]		0.054		0.8
Frying[3]		0.108		0.1
Oven[4]			0.33	0.1
Deep frying[5]			0.67	-
Washing up[6]			0.28	

3.5 Carbon footprints of the inputs

The carbon footprints of various types of input to the cultivation and processing are given in Table 3.8. The figure for the carbon footprint of manure was calculated according to the best method by Blonk Environmental Consultants (calculation rules of the Dutch NIR 2010) and multiplied by a working coefficient of 60%. The figures calculated using alternative methods (no allocation of nitrous oxide emissions via the soil and/or calculation rules according to the Tier 1 method in the IPCC 1996 and 2006 Guidelines) are shown in Table 3.9. For chemical fertilizer, the carbon footprint was divided between production and use (nitrous oxide emissions via the soil). The figure for use was calculated according to the calculation rules in the Dutch NIR 2010 (8.3 kg CO_2 eq per kg N). Using the Tier 1 method in the IPCC 1996 and 2006 Guidelines, the figure is 9.8 and 6.2 kg CO_2 eq per kg N, respectively (Table 3.9).

Table 3.8: Carbon footprints of the inputs (source: Blonk Milieu Advies)

Input	Unit	Value	Remarks
Manure	kg CO_2 eq per kg	8.0	Working coefficient for slurry is 60%
N in chemical fertilizer (use)	kg CO2 eq per kg	8.3	Specific to KAS
N in chemical fertilizer (production)	kg CO_2 eq per kg	8.1	Specific to KAS
K_2O in chemical fertilizer	kg CO_2 eq per kg	0.44	Production
P_2O_5 in chemical fertilizer	kg CO_2 eq per kg	1.5	Production
Diesel	kg CO_2 eq per kg	3.6	Based on Ecoinvent
N in crop residues	kg CO_2 eq per kg	8.2	Direct and via leaching
Electricity	kg CO_2 eq per kWh	0.52	Supply mix (2006–2009)
Natural gas	kg CO_2 eq per m^3	1.89	Specific to the Netherlands
Packaging material	kg CO_2 eq per kg	3.8	Ecoinvent plus waste-to-energy incinerator in the Netherlands
Vegetable oil (sunflower)	kg CO_2 eq per kg	2.3	Own data

Table 3.9: Example of nitrous oxide emissions following field-application of manure that can be allocated entirely (100%) or partly (60%) to cultivation, in kg CO_2 eq per kg N

Parameter	IPCC 1996	IPCC 2006	NIR NL 2010
		(kg CO_2 eq/kg N)	
Nitrous oxide emission from manure (100%)	10.3	6.7	13.3
Nitrous oxide emission from manure (60%)	6.2	4.0	8.0
Nitrous oxide emission from chemical fertilizer (KAS)	9.8	6.2	8.3

4 Results and discussion

4.1 Overall picture of emissions and uptake of greenhouse gases in the table potato supply chain

Figure 4.1 gives an overall picture of the emissions and uptake of greenhouse gases in the table potato supply chain. The emissions are expressed in kg CO_2 equivalents per tonne of table potatoes sold in the shops.

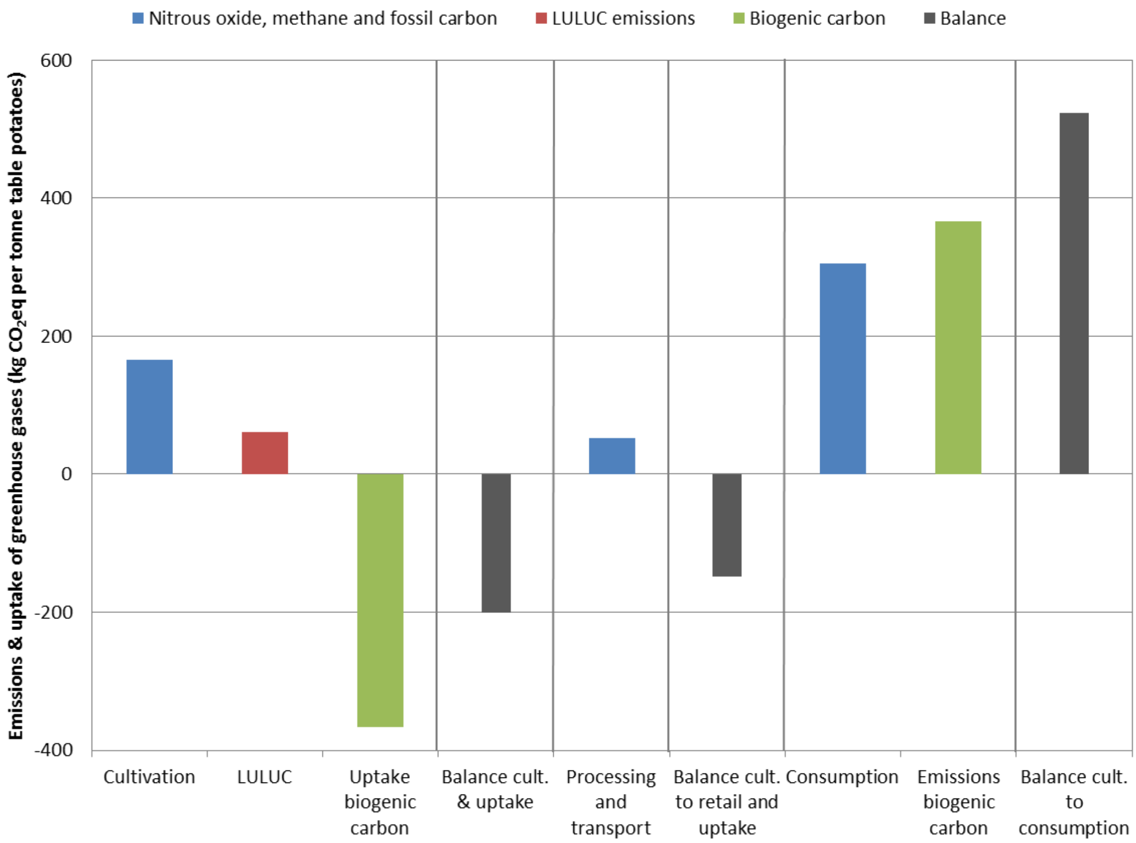

Figure 4.3: Overall picture of the emissions and uptake of greenhouse gases in the table potato supply chain

4.2 Carbon footprints of table potatoes

We present here three different types of carbon footprint for table potatoes based on information in the most recent versions of the various standards. These are a cradle-to-farm gate, a cradle-to-retail point and a cradle-to-grave carbon footprint. The uptake and emission of biogenic carbon is not visible in the three carbon footprints, because the release of biogenic carbon in the later life-cycle stages is certain and because the product has a relatively short shelf life.[8] Neither are the LULUC emissions shown, because there is as yet no consensus on how these should be calculated and reported. Figure 4.2 is a graphic representation of the carbon footprints. The cradle-to-gate carbon footprints of table potatoes (in round figures) are 170 and 220 kg CO_2eq per tonne of table potatoes to the farm gate and to the retail point respectively. The latter is more or less the same as the carbon footprint of leeks, Dutch apples and

[8] ISO 14067 and PAS 2050 are both evolving and the relevant sections on this aspect may yet change. An unresolved issue is how to deal with the long-term release of biogenic carbon (at least after a period of ten years). The question is whether this should be dealt with differently than for short-term biogenic carbon emissions.

summer cauliflower. Converted to dry matter figures, the footprint of table potatoes is 1100 kg CO_2eq per tonne dry matter. For comparison, the cradle-to-gate carbon footprints of pasta and rice are between 1000 and 2500 kg CO_2eq per tonne dry matter.

The cradle-to-grave carbon footprint of table potatoes is 520 kg CO_2eq per tonne of table potatoes. This means that the production of table potatoes, including transport to the shops accounts for just 42% of the total carbon footprint. In terms of dry matter, this value is roughly the same as the carbon footprint of rice and is higher than that of bread or pasta. The major part of the carbon footprint is caused by electricity use for the oven, natural gas consumption for cooking and the use of the dishwasher. However, for table potatoes these can be considerably reduced. Less use of the oven can reduce the carbon footprint by up to 10%. The consumption of natural gas for cooking can be reduced by using a pressure cooker, by cooking larger amounts of potatoes in a single batch and by cutting the potatoes into slices or blocks before cooking them. The consumption of energy by the dishwasher can be reduced by using an energy saving programme or a more energy-efficient model of dishwasher.

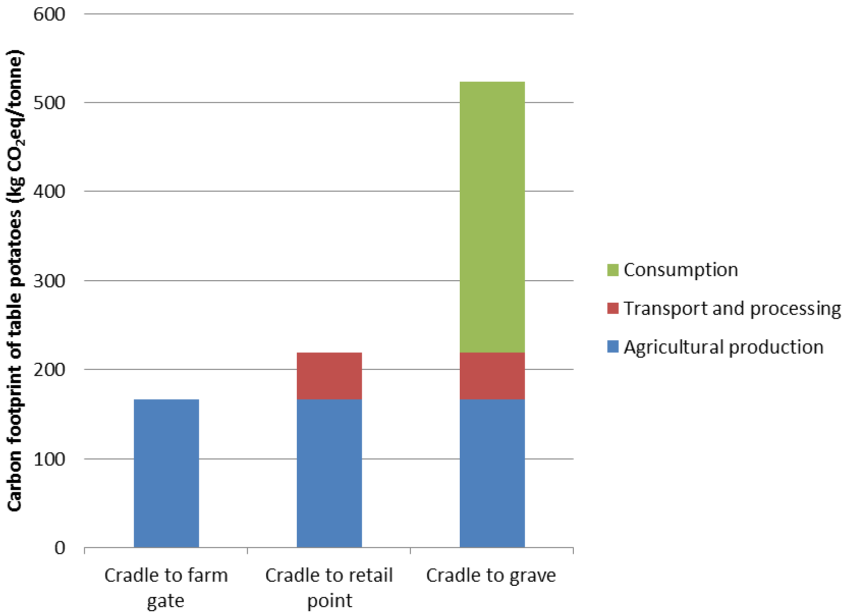

Figure 4.2: Carbon footprints of table potatoes

Effect of the choice of method on the results

In this study, 60% of the nitrous oxide emissions following manure applications are allocated to the cultivation stage of the life cycle. If 100% of the nitrous oxide emissions following manure applications are allocated to cultivation, the cradle-to-retail point carbon footprint is almost 7% higher. If the nitrous oxide emissions are calculated according to the Tier 1 method in the IPCC Guidelines of 1996 and 2006, the carbon footprint is 2% higher and 10% lower respectively.

Contribution by the different sources and reduction potential

Appendix 2 contains the footprint results for all the emission sources. By far the majority of greenhouse gas emissions in the cradle-to-retail point carbon footprint of table potatoes are related to cultivation (almost 76%). The biggest emission sources are the production of nitrogen fertilizer (15%), soil nitrous oxide emissions from chemical fertilizer use (16%) and electricity consumption for cold storage of ware potatoes (20%). The reduction potential of the carbon footprint lies primarily in these sources.

In principle, more efficient use of fertilizer will deliver a reduction in greenhouse gas emissions. However, the use of fertilizer in the Netherlands is highly efficient, in part because of the fertilizer legislation. By using more manure and less chemical fertilizer, the carbon footprint could be reduced by about 10% while maintaining the same level of yield. This can be achieved despite the fact that low-emission manure application techniques release twice the amount of direct nitrous oxide emissions per kg nitrogen than the application of nitrogen in the form of chemical fertilizer (according to the Dutch NIR). An advantage of manure nitrogen over chemical fertilizer is that no emissions are allocated to manure production. However, this reduction only applies if part of the nitrous oxide emissions from the application of manure is allocated to plant production, as in this study.

Reducing the electricity consumption for cold storage by a quarter would reduce the carbon footprint by 5%. Using alternative sources of electricity, for example by using electricity from solar panels on shed roofs, could bring about a similar reduction.

4.3 Overall picture of emissions and uptake of greenhouse gases in the frozen chips supply chain

Figure 4.3 gives an overall picture of the emissions and uptake of greenhouse gases in the frozen chips supply chain. The emissions are expressed as kg CO_2 equivalents per tonne of frozen chips sold in the shops.

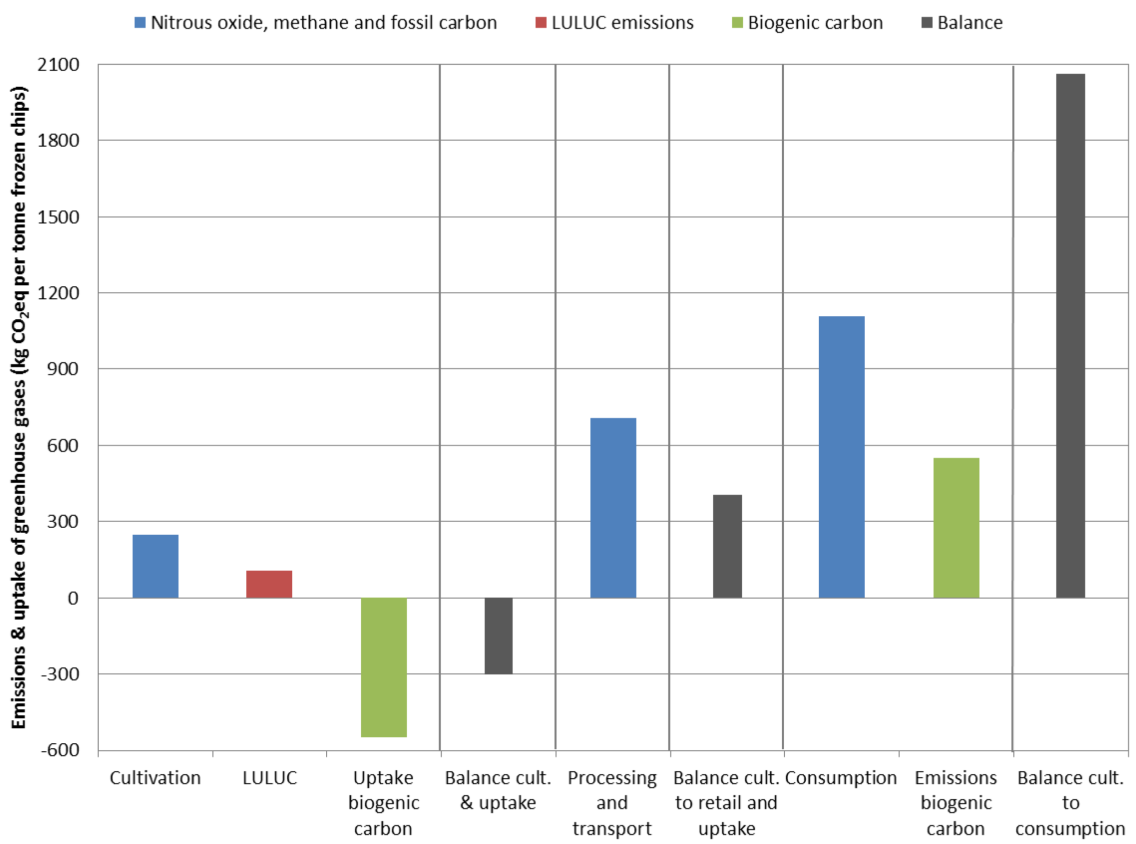

Figure 4.3: Overall picture of the emissions and uptake of greenhouse gases in the frozen chips supply chain

4.4 Carbon footprints of frozen chips

We present here three different types of carbon footprint for frozen chips according to the most recent versions of the various standards. These are a cradle-to-farm gate, a cradle-to-retail point and a cradle-to-grave carbon footprint. As in the carbon footprint of table potatoes (see 4.2), the uptake and emission of biogenic carbon is not visible in these three carbon footprints, and neither are the emissions attributed to LULUC shown. The cradle-to-farm gate carbon footprint of frozen chips is 250 kg CO_2eq per tonne of frozen chips and the cradle-to-retail point footprint is 950 kg CO_2eq per tonne. The latter is higher than the cradle-to-gate carbon footprint of frozen French beans (700 kg CO_2eq per tonne) and frozen peas (600 kg CO_2eq per tonne) and is about the same as the paprika footprint (900 kg CO_2eq per tonne).

The cradle-to-grave carbon footprint of chips is 2060 kg CO_2eq per tonne of chips. This is almost four times as high as the cradle-to-grave carbon footprint of table potatoes. It is not easy to conclude whether the cradle-to-grave carbon footprint of fried frozen chips is lower than that of chips made from fresh potatoes. The carbon footprint of chips made from fresh potatoes involves higher emissions due to less efficient pre-frying and because the potato peelings are not sold as animal feed, but emissions are reduced because no energy is used for freezing.

Almost half the cradle-to-grave footprint of frozen chips can be attributed to electricity consumption and vegetable oil use for deep frying. The electricity consumption per kg of chips can be reduced by frying more chips in consecutive batches, which would considerably reduce the carbon footprint. Chips made in a busy snack bar or a fast-food chain will therefore have a much lower cradle-to-grave carbon footprint.

The use of frying oil accounts for over a quarter of the carbon footprint. However, this can be much more variable because the oil can be reused more or less frequently. Moreover, other products can be deep fried using the same fat, which causes allocation problems. There are also different deep fryers on the market, with different powers and capacities. Some new deep fryers need much less oil to fry the same amount of chips because they have an 'oil spray' system, which makes them more energy efficient by heating up more quickly.

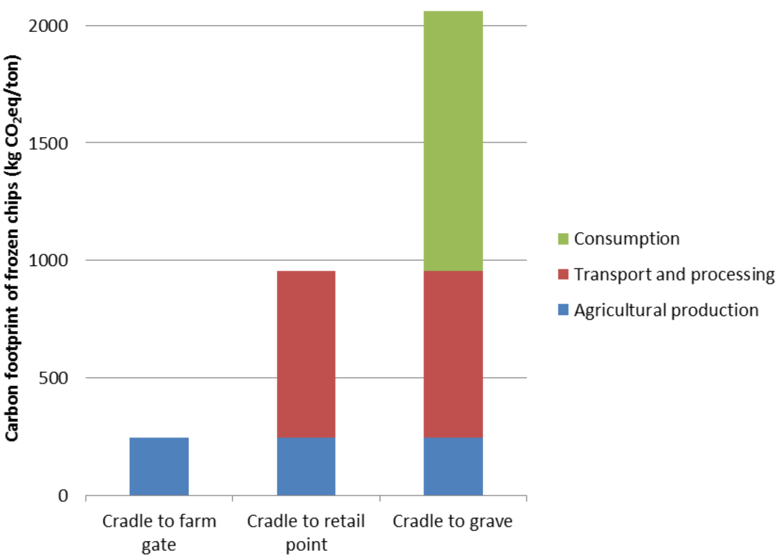

Figure 4.4: Carbon footprints of frozen chips

Choice of method

If all the nitrous oxide emissions from manure application are allocated to cultivation, the cradle-to-retail point carbon footprint is only 2% higher. This very small effect is mainly because nitrous oxide emissions from manure application only make a small contribution to the carbon footprint. The carbon footprint is about the same if the nitrous oxide emissions are calculated according to the Tier 1 method in the IPCC 1996 Guidelines. This is because the nitrous oxide emissions from chemical fertilizer are then higher and the emissions from manure are lower. The carbon footprint calculated according to the Tier 1 method in the IPCC 2006 Guidelines is 3% lower than when it is calculated using the method employed in this study.

Contribution by the different sources

Appendix 3 contains the footprint results for all the emission sources. About 26% of the greenhouse gas emissions in the cradle-to-retail point carbon footprint of frozen chips are related to cultivation, whereas almost 75% are attributed to processing. The biggest source of emissions are 1) natural gas for chip production (30%), 2) electricity for chip production – mainly freezing the chips (14%), 3) vegetable oil (13%), 4) cooling in the shop (11%) and 5) electricity for cold storage of ware potatoes (7%). The reduction potential of the carbon footprint lies primarily in the processing of ware potatoes into frozen chips.

5 Conclusions and recommendations

5.1 Carbon footprints

The cradle-to-retail point carbon footprint of table potatoes is 220 kg CO_2 eq per tonne. This is low compared with other carbohydrate-rich products, such as rice and pasta, even if the calculation is made in tonnes and on a dry matter basis. The main contribution to the carbon footprint is the use of fertilizer and electricity consumption for storage. The reduction potential is to be found mainly in these emission sources. However, the cradle-to-grave carbon footprint (520 kg CO_2 eq per tonne) does not differ much from comparable (carbohydrate-rich) products if it is expressed per tonne of dry matter. There is considerable potential for reduction in the user phase (mainly in the preparation stage) of table potatoes, which can bring the footprint down to a relatively low level.

The cradle-to-retail point carbon footprint of frozen chips is 950 kg CO_2 eq per tonne. This is comparable with the footprint of frozen French beans, frozen peas and paprika. The reduction potential lies mainly in the consumption of natural gas for the production of the chips. In addition, the electricity used for freezing the pre-fried chips in the chip production stage makes an important contribution to the carbon footprint. The cradle-to-grave carbon footprint (2060 kg CO_2 eq per tonne) is almost four times as high as the footprint of table potatoes (Table 5.1). In both cases, there is great potential for reduction in the user phase, for example by using a pressure cooker instead of a standard pan for cooking table potatoes and purchasing an energy-efficient deep fryer with an oil spray system.

Table 5.1: Carbon footprints of table potatoes and frozen chips

Product	Unit	Table potatoes	Frozen chips
Cradle-to-farm gate	kg CO_2 eq/tonne	170	250
Cradle-to-retail point	kg CO_2 eq/tonne	220	950
Cradle-to-grave	kg CO_2 eq/tonne	520	2060

5.2 Recommendations on methodological choices

The calculation of the carbon footprints of potato products involves making a number of methodological choices. These choices all have to do with the soil nitrous oxide emissions:

- partial or complete allocation of manure nitrous oxide emissions to cultivation;
- allocation of manure nitrous oxide released in the second year over the cropping plan and allocation of crop residues over the cropping plan;
- use of emission factors from the Dutch NIR, the Tier 1 method in the 1996 or 2006 IPCC Guidelines.

Partial or complete allocation of manure mainly influences the cradle-to-gate carbon footprint of table potatoes. Blonk Environmental Consultants advises the Product Board for Animal Feed, the Commodity Board for Arable Products and other organizations to adopt the allocation method used here, in which the nitrous oxide emissions are only partly allocated to cultivation, as a standard method.

Allocation of manure nitrous oxide released in the second year over the cropping plan has a limited effect on the carbon footprints of potato products. Allocation of crop residues may well make a significant difference, but this depends on the specific cropping plan. For this reason, Blonk Environmental

Consultants advises using this allocation method only if detailed information about the cropping plan is available. When looking for improvement options it is recommended that this information should be collected and the effects calculated at the cropping plan level.

The Tier 1 emission factors in the IPCC 2006 Guidelines differ from those in the previous Guidelines and in the Dutch NIR to such an extent that the resulting carbon footprint is significantly lower. We recommend working with the Dutch NIR because this is more detailed and is based on sound research. However, for comparisons with other studies it is important to realize which emission factors are used in the calculations of soil nitrous oxide emissions. The emission factors in the various NIRs, for example, may be very different and deviate from the Tier 1 emission factors in the IPCC Guidelines.

5.3 Recommendations for LULUC and biogenic carbon

There is as yet no consensus among LCA professionals on how to calculate the greenhouse gas emissions from land use and land use change (LULUC). We advise using the method for calculating LULUC emissions described in the protocol for calculating the carbon footprints of horticultural products, but to report this separately.

Vegetable products contain biogenic carbon derived from the uptake of CO_2 by the crop. Because in most cases the stored carbon is released within a year as a result of oxidation, the uptake and emissions are often not explicitly reported. Our recommendation is to report the uptake and emission of biogenic carbon, but separately from the fossil CO_2 emissions, methane and nitrous oxide emissions.

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Appendix 1: GWP factors

Table A.1.1 shows the most recent global warming potential (GWP) factors of five different important greenhouse gases, including methane and nitrous oxide gas (IPCC 2007). Table A1.2 shows the GWP factors from IPCC (2001) and Table A1.3 shows the GWP factors from IPCC (1996).

Table A1.1 GWP factors from IPCC (2007)

Greenhouse gas	Lifetime (years)	GWP-20	GWP-100	GWP-500
Methane	12	72	**25**	7.6
Nitrous oxide	114	289	**298**	153
HFC-23 (hydrofluorocarbon)	270	12000	14800	12200
HFC-134a (hydrofluorocarbon)	14	3830	1430	435
Sulphur hexafluoride	3200	16300	22800	32600

Table A1.2 GWP factors from IPCC (2001)

Greenhouse gas	Lifetime (years)	GWP-20	GWP-100	GWP-500
Methane	12	62	23	7.6
Nitrous oxide	114	275	296	153
HFC-23 (hydrofluorocarbon)	260	9400	12000	12200
HFC-134a (hydrofluorocarbon)	13.8	3300	1300	435
Sulphur hexafluoride	3200	15100	22200	32600

Table A1.3 GWP factors from IPCC (1996)

Greenhouse gas	Lifetime (years)	GWP-20	GWP-100	GWP-500
Methane	12	56	21	6.5
Nitrous oxide	120	280	310	170
HFC-23 (hydrofluorocarbon)	264	9100	11700	9800
HFC-134a (hydrofluorocarbon)	14.6	3400	1300	420
Sulphur hexafluoride	3200	16300	23900	34900

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Appendix 2: Contribution by emission sources in the carbon footprints of table potatoes

The table below lists the contributions by various emission sources to the carbon footprints of table potatoes.

	Carbon footprint kg CO_2eq/tonne	Cradle-to-farm gate	Cradle-to-retail point	Cradle-to-grave
Cultivation				
Seed material	8	5%	4%	2%
N in chemical fertilizer (production)	33	**20%**	**15%**	6%
N in chemical fertilizer in the soil	34	**21%**	**16%**	7%
N in manure	20	12%	9%	4%
Phosphate and potash in chemical fertilizer	5	3%	2%	1%
Diesel	13	8%	6%	2%
N in crop residues	9	5%	4%	2%
Electricity (cold storage)	44	**27%**	**20%**	8%
Transport and processing				
Transport from grower to processor	5	-	2%	1%
Natural gas	2	-	1%	0%
Electricity	4	-	2%	1%
Packaging material	27	-	12%	5%
Transport to DCs and shops	15	-	7%	3%
Consumption				
Transport	35	-	-	7%
Storage	5	-	-	1%
Cooking	82	-	-	**16%**
Frying	20	-	-	4%
Oven	17	-	-	3%
Washing up	146	-	-	**28%**
Total	**524**	**100%**	**100%**	**100%**

Appendix 3: Contribution by emission sources in the carbon footprints of frozen chips

The table below lists the contributions by various emission sources to the carbon footprints of frozen chips.

	Carbon footprint (kg CO_2eq/tonne)	Cradle-to-farm gate	Cradle-to-retail point	Cradle-to-grave
Cultivation				
Seed material	11	4%	1%	1%
N in chemical fertilizer (production)	45	18%	5%	2%
N in chemical fertilizer in the soil	46	19%	5%	2%
N in manure	27	11%	3%	1%
Phosphate and potash in chemical fertilizer	10	4%	1%	0%
Diesel for use in cultivation	32	13%	3%	2%
N in crop residues	12	5%	1%	1%
Electricity (cold storage)	65	26%	7%	3%
Transport and processing				
Transport from grower to processor	7	-	1%	0%
Natural gas for chip production	279	-	29%	14%
Electricity for chip production	132	-	14%	6%
Packaging material	40	-	4%	2%
Vegetable oil	121	-	13%	6%
Transport to DCs and shops	22	-	2%	1%
Cooling in the shop	104	-	11%	5%
Consumption				
Transport to consumer	35	-	-	2%
Storage by consumer	5	-	-	0%
Vegetable oil	575	-	-	28%
Electricity for deep frying	347	-	-	17%
Electricity for washing up	146	-	-	7%
Total	**2061**	**100%**	**100%**	**100%**