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Arla Foods Environmental Profit and Loss Accounting 2014

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Arla Foods Environmental Profit and Loss Accounting 2014Arla Foods Environmental Profit and Loss Accounting 2014

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Preface

This study is partially financed by the Danish Environmental Protection Agency (EPA). From Arla's side, the following persons were involved: Birgitte Koch (Project leader), Jan D. Johannesen, Anette Gersbøll, Anna Flysjö, Hanne Bligaard, and Christopher Brunhøj. 2.-0 LCA consultants represented by Jannick H. Schmidt and Marie de Saxcé were responsible for modelling, production of results as well as reporting.

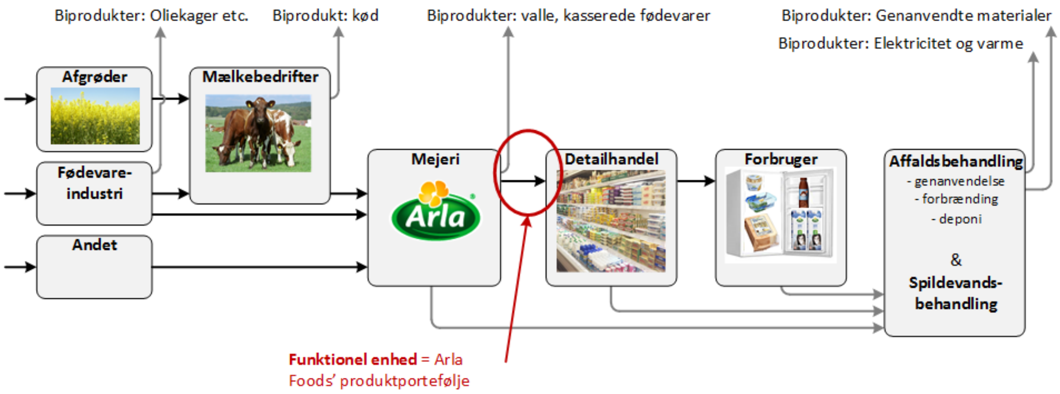
Sammenfatning og konklusion

Introduktion

Som et led i dokumentationen af miljøpåvirkninger fra deres samlede produktportefølje har Arla Foods fået udarbejdet en Environmental Profit and Loss Account (E P&L). En E P&L opgørelse opgør miljøpåvirkningen i livscyklus fra summen af alle produkter fra en virksomhed i økonomiske enheder. Værdisætningen er et trin, som bygger ovenpå opgørelsen af miljøpåvirkninger i deres fysiske enheder.

Formålet med E P&L opgørelsen er, at bruge resultaterne til at evaluere Arla's miljømæssige strategi for 2020 for at sikre at fokus er på de vigtigste områder. Desuden påtænkes resultaterne at blive brugt i kommunikation af miljøforhold, og herunder at underbygge, at Arla tager sit miljømæssige ansvar alvorligt, og at de tager ansvar for hele værdikæden.

Analysen fokuserer på miljøpåvirkningen fra alle Arla's aktiviteter i 2014. Således inkluderes alle livscykluspåvirkninger fra vugge til grav fra summen af hele Arla Foods produktportefølje i 2014. Produktsystemet er illustreret i figuren nedenfor.



FIGUR. ILLUSTRATION AF PRODUKTSYSTENMET RELATERET TIL ARLA FOODS PRODUKTER. DE GRÅ PILE REPRÆSENTERER BIPRODUKTER OG AFFALDSSTRØMME.

Arla Foods' produktportefølje i 2014 omfatter 7.68 millioner tons mejeriprodukter og 1.32 millioner tons biprodukter (valle og kasserede fødevarer som sælges som dyrefoder). Ud af de 7.68 millioner tons mejeriprodukter er 5.55 millioner tons friske mejeriprodukter (mælk, yoghurt, fløde etc.) og 0.68 millioner tons er ost. Resten er valle- og mælkepulver, smør og ikke-mælke-baserede produkter (primært frugtjuice).

E P&L opgørelsen inkluderer alle Arla Foods fabrikker samt datterselskaberne Arla Foods Ingredients, Rynkeby og Cocio. Joint ventures er ikke inkluderet. Alle Arla Foods fabrikker, distributionscentre og administrative enheder (99 sites i 12 lande) er inkluderet. Udvinding og fremstilling af råvarer, brændsler og elektricitet, emballage og transport (til og fra Arla) er inkluderet. Desuden er behandling, forarbejdning og anvendelse af biprodukter og affald inkluderet. Herudover er produkter og services, som ikke indgår direkte i Arla's produktion også omfattet, fx computere, møbler, forretningsrejser, bygninger, maskiner etc. Nedstrøms livscyklusfaser (detailhandel, forbrug og affaldsbehandling) er også inkluderet.

Metoder

For at beregne livscyklusemissioner, anvendes metoden livscyklusvurdering (LCA). LCA er en metode, hvor alle emissioner og ressource fra alle aktiviteter i et produktsystem opgøres. På baggrund af de opgjorte livscyklusemissioner og –ressourcer, beregnes livscykluspåvirkninger. Resultater præsenteres både som fysiske påvirkninger (fx kg CO_2-ækvivalenter) og som monetariserede påvirkninger. Fysiske påvirkninger omfatter fx drivhuseffekt, respiratoriske effekter, naturbeslaglæggelse (biodiversitet), og monetariserede påvirkninger beregnes som summen på påvirkninger på sundhed, økosystemer og ressourcer i økonomiske enheder.

Til beregning af livscyklus emissioner og ressourcer i LCA anvendes ofte to forskellige metoder: konsekvenstilgangen og attributional-tilgangen. Nærværende studie præsenterer resultater bergenet med begge tilgange. Boksen til højre forklarer kort forskellen i fokus ved de to forskellige tilgange. Konsekvens-tilgangen følger retningslinjer i (ISO 2006; Weidema 2003; Weidema et al. 2009) og attributional-tilgangen følger retningslinjerne i (IDF 2010).

Kortlægningen af emissioner og ressourcer i livscyklus af Arla's produkter medtager det forhold, at anvendelse af land bidrager til at øge presset på omdannelse af natur til produktiv land. Omlægning af natur til produktiv land sker oftest i andre dele af verdenen end hvor dyrkning af afgrøder til foder foregår. Eksempelvis vil anvendelse af en hektar i et år i Danmark påvirke afskovning i andre dele af verdenen, fx i Sydamerika og Sydøstasien.

To LCA tilgange, to sæt af resultater, og svar på to forskellige spørgsmål

Konsekvens LCA giver et svar på spørgsmålet: "*hvad er konsekvensen af et valg*?" Dette valg kan være at købe eller producer et produkt eller at implementere en forbedring. Konsekvens LCA er relevant, når Arla ønsker at kende konsekvenserne af deres handlinger.

Attributional LCA giver et svar på spørgsmålet: "*hvad er påvirkningerne fra den andel af livscyklussen, som det er besluttet at inkludere baseret på en normative allokering og cut-off regel?"* Attributional LCA er relevant, når Arla ønsker at rapportere deres miljøpåvirkninger i overensstemmelse med konsensusbaserede guidelines/standarder.

BOX. CONSEQUENTIAL ANDATTRIBUTIONAL LCA – TWO WAYS OF MODELLING A PRODUCT SYSTEM IN LCA.

Omdannelse af skov til landbrugsland medfører en ændring i, hvor meget biodiversitet det givne areal indeholder, og i mængden af opbevaret kulstof i plantemateriale på arealet. En ændring a lagret kulstof medfører CO_2 emissioner. Disse bidrag til påvirkninger på biodiversitet og CO_2 emissioner er her kaldet indirekte land use changes (iLUC). Da attributional LCA normalt ikke inkluderer iLUC, er dette kun medtaget ved beregning af resultater med konsekvenstilgangen.

Beregning af fysiske og monetariserede resultater er baseret på Stepwise-metoden (Weidema et al. 2007; Weidema 2009). Stepwise-metoden anvender bredt anerkendte metoder til beregning af fysiske påvirkninger, fx er drivhuseffekt beregnet i overensstemmelse med IPCC's "global warming potential" (GWP100). Værdisætningstrinnet i LCA anvendes i langt mindre omfang end opgørelse af påvirkninger i fysiske enheder. Derfor findes der ikke på same måde, som for de fysiske resultater, bredt anerkende metoder. Udover at anvendte Stepwise-metoden til værdisætning, er dette også udført ved anvendelse af Miljøstyrelsens anbefalede værdisætning af emissioner samt en metode udviklet af Trucost. Disse metoder har været anvendt i tidligere E P&L opgørelser publiceret af Miljøstyrelsen.

Hovedresultater

Alle resultater er opgjort for summen af Arla Food's produktportefølje i 2014. Ved anvendelse af værdisætningen i Stepwise-metoden er de følgende miljøpåvirkningskategorier identificeret, som de mest vigtige:

- Drivhuseffekt (CO_2, CH_4, N_2O)
- Respiratoriske effekter (luftemissioner: partikler, ammoniak, NO_x, SO_2)
- Naturbeslaglæggelse (biodiversitet)

Resultater beregnet ved attributional-tilgangen viser at terrestrisk eutrofiering også er vigtig (dog væsentligt mindre end drivhuseffekt og respiratoriske effekter).

Identificeringen af de ovennævnte miljøpåvirkningskategorier som de vigtigste er konfirmeret ved anvendelse af andre vægtningsmetoder til LCA samt andre værdisætningsmetoder. De andre LCA vægtningsmetoder peger også på forbrug af ikke-fornybar energi som en anden vigtig miljøpåvirkningskategori. I tillæg til de ovennævnte miljøpåvirkningskategorier er der også medtaget fysiske resultater for vand (m^3) og arealbeslaglæggelse (hektar*år). Disse miljøpåvirkningskategorier er ikke monetariserede: Arealbeslaglæggelse er et bidragende flow til naturbeslaglæggelse, og vand er ikke inkluderet i Stepwise-metoden.

Resultater i fysiske enheder

De beregnede fysiske resultater for miljøpåvirkningerne er præsenteret i tabellen nedenfor.

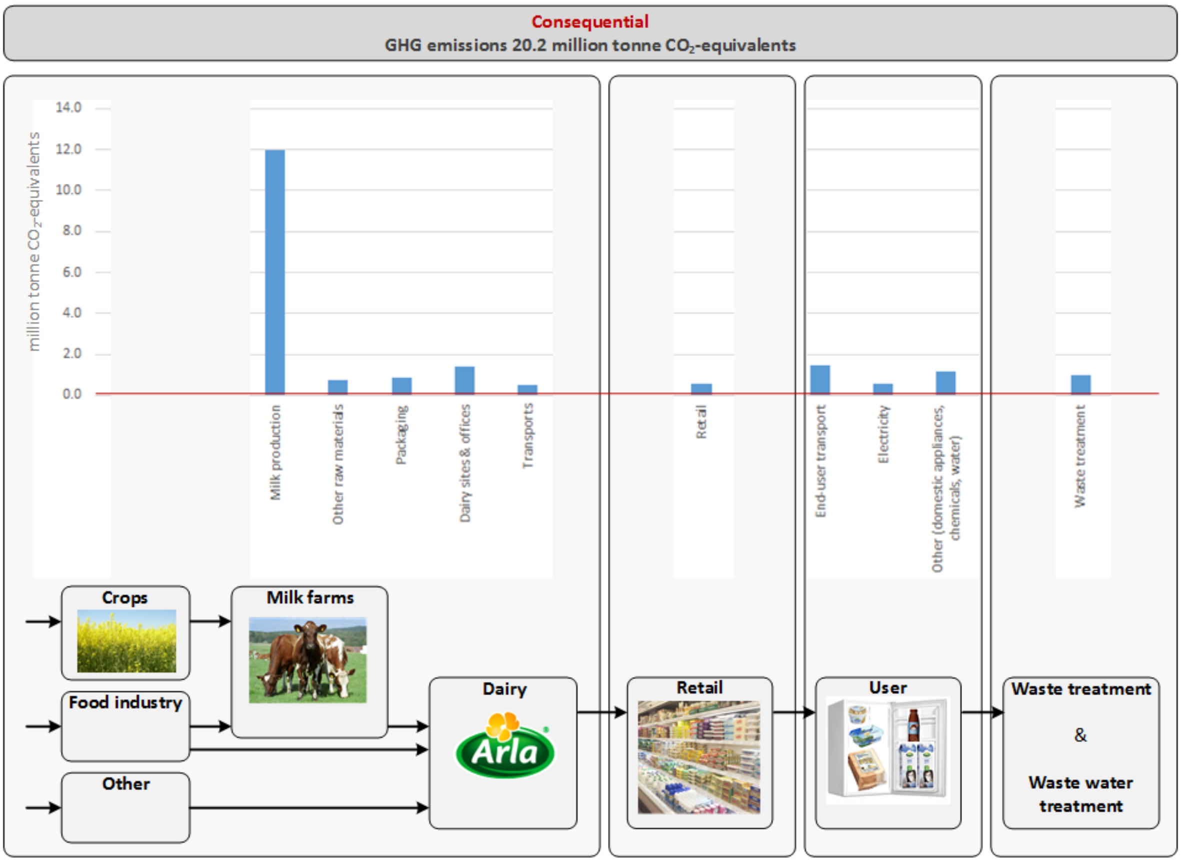
TABLE: MILJØPÅVIRKN INGER I FYSISKE ENHEDER. RESULTATERNE ER VIST FOR DE TO TILGANGE TIL MODELLERING I KORTLÆGNINGEN I LCA: KONSEKVENSTILGANGEN (BASERET PÅ ÅRSAGSVIRKNINGSSAMMENHÆNGE) OG ATTRIBUTIONAL-TILGANGEN (BASERET PÅ NORMATIVE REGLER).

Miljøpåvirkningskategori	Enhed	Indikatorresultater	
		Konsekvens LCA	Attributional LCA
Stepwise. Disse miljøpåvirkninger er monetariseret			
Drivhuseffekt	millioner tons CO_2-ækv	20.2	26.6
Respiratoriske effekter (inorg)	tons $PM_{2.5}$-ækv	23,551	19,018
Respiratoriske effekter (org)	millioner pers*ppm*h	14	22
Naturbeslaglæggelse	PDF*ha*år	544,000	-26,000
Forsuring	ha UES	385,000	287,000
Eutrofiering, terrestrisk	ha UES	1,626,000	1,139,000
Eutrofiering, akvatisk	tons NO_3-ækv	540,000	376,000
Fotokemisk ozondannelse, vegetat.	millioner ha*ppm*timer	14	21
Humantoksicitet, kræftfremkaldende	tons C_2H_3Cl-ækv	232,000	144,000
Humantoksicitet, ikke-kræft	tonne C_2H_3Cl-ækv	129,000	94,000
Økotoksicitet, akvatisk	millioner tons TEG-ækv	492	404
Økotoksicitet, terrestrisk	millioner tons TEG-ækv	63	50
Ioniserende stråling	millioner Bq C-14-ækv	54,000	188,000
Ikke-fornybar energi	TJ primær	136,000	164,000
Mineral udvinding	TJ ekstra	740	618
Ekstra indikatorer. Disse er ikke monetariseret			
Arealbeslaglæggelse	millioner ha	-3.63	2.74
Vand (blue water footprint)	millioner m^3	194	293

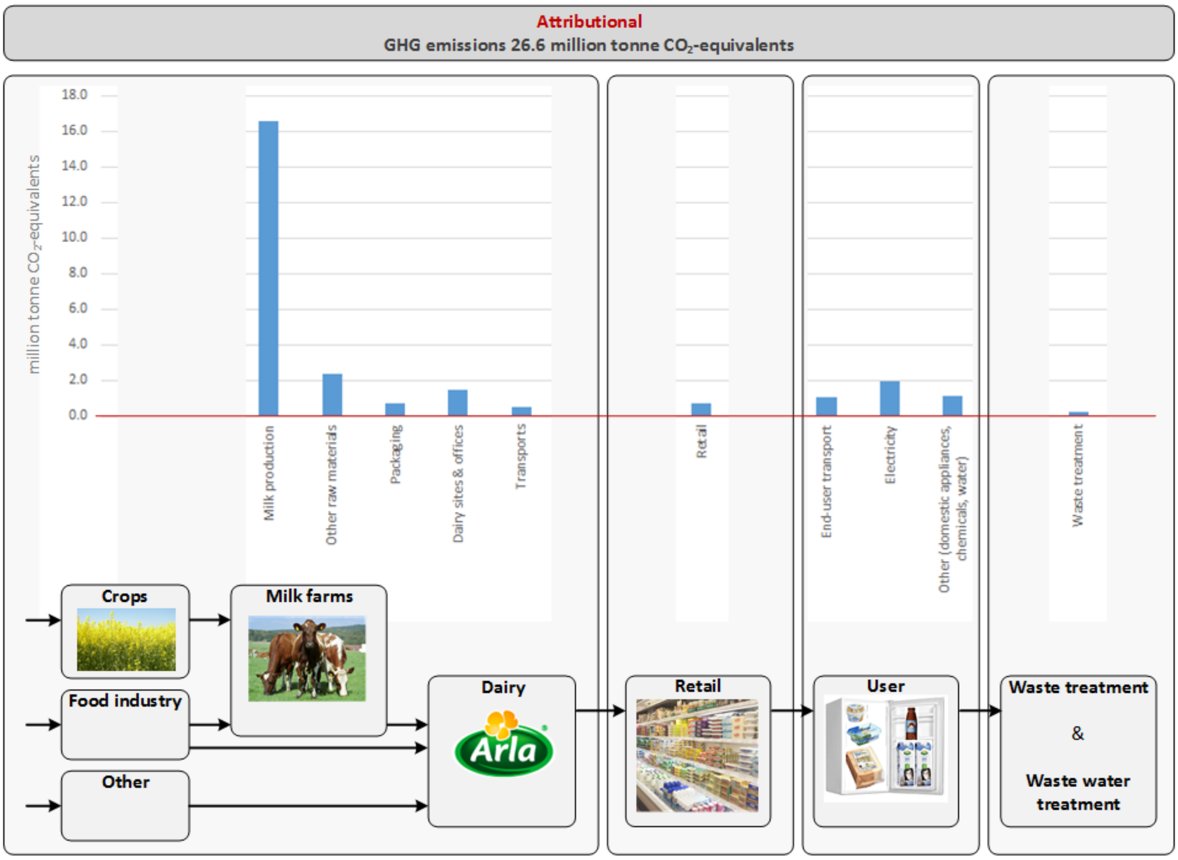
Størstedelen af påvirkningerne er relateret til aktiviteter i landbruget: dyre- og foderproduktion. Således viser en bidragsanalyse, at 59% (konsekvens) og 62% (attributional) af de samlede livscyklus drivhusgas emissioner fra Arla Foods' produktportefølje er relateret til fremstilling af råmælk i landbruget. Fremstillingen af mælk dominerer også for de andre miljøpåvirkningskategorier – undtaget naturbeslaglæggelse i attributional-tilgangen, som giver et lille negativt resultat. Årsagen hertil er, at attributional-tilgangen ikke inkluderer indirekte land use changes (iLUC), hvor størstedelen af påvirkningen af naturbeslaglæggelse sker. Resultater beregnet ved attributional-tilgangen inkluderer kun direkte land use changes: Da ekstensive vedvarende græs indeholder mere biodiversitet end den alternative anvendelse af disse arealer, bliver naturbeslaglæggelse herfra negativ.

Et andet resultat, som bør forklares lidt nærmere er arealbeslaglæggelse beregnet ved konsekvens-tilgangen. Årsagen til at dette resultat er negativt er, at konsekvens-tilgangen inkluderer alt arealbeslaglæggelse ved mælkeproduktionen og fratrækker (substituerer) alt arealbeslaglæggelse, som relaterer sig til biproduktet fra mælkeproduktion; kød. Således inkluderer det negative resultat et positivt bidrag fra mælkesystemet og et større negativt bidrag fra fortrængt kødkvægsproduktion i Brasilien, som anses for at være den marginale leverandør af oksekød på verdensmarkedet. Årsagen til at nettoarealbeslaglæggelsen bliver negative er, at den substituerede kvægproduktion i Brasilien er meget ekstensiv, dvs. at dyretætheden på græsningsarealerne er meget lav. Det bør desuden nævnes, at den samlede påvirkning af naturbeslaglæggelse (biodiversitet) ikke er negativ. Dette er fordi den fortrængte beslaglæggelse af græsningsarealer ikke har en så høj påvirkning på biodiversitet per areal, som beslaglæggelse af det landbrugsland, hvor mælkeproduktionen foregår

De følgende to figurer giver et detaljeret overblik bidrag til drivhusgasemissioner fra de forskellige livscyklusfaser. Den første figur viser resultater for konsekvens-tilgangen, og den efterfølgende viser resultater for attributional-tilgangen.



FIGUR. ILLUSTRATION OF BIDRAGENE TIL DRIVHUSEFFEKT FRA DE FORSKELLIGE LIVSCYKLUSFASER. **KONSEKVENS LCA**.



FIGUR. ILLUSTRATION OF BIDRAGENE TIL DRIVHUSEFFEKT FRA DE FORSKELLIGE LIVSCYKLUSFASER. **ATTRIBUTIONAL LCA**.

Resultater i monetære enheder

De monetariserede resultater udtrykker skadevirkningen forårsaget af eksternaliteter relateret til Arla Foods produktportefølje. De monetariserede påvirkninger kan sammenlignes med Arla Foods omsætning på 10,600 million EUR i 2014, som indikerer Arla's værdiskabelse.

De monetariserede resultater for konsekvens- og attributional- tilgangen er henholdsvis 1840-5850 og 2240-4980 millioner EUR. Intervallerne repræsenterer resultater opnået ved anvendelse af forskellige værdisætningsmetoder. Det fremgår, at de værdisatte resultater er meget afhængige af valg af værdisætningsmetode. Nedenfor i tabellen er forskellene i de værdisatte resultater forklaret for hver metode.

Konklusionen er at Stepwise viser højeste værdisatte resultater fordi værdien af drivhusgasser, ammoniak og naturbeslaglæggelse er høj. Miljøstyrelsens anbefalede metode viser lavere resultater, fordi drivhusgasser er værdisat lavt (følger kvoteprisen på CO_2) og fordi naturbeslaglæggelse ikke er værdisat. Trucosts metode viser lavere resultater, fordi ammoniak er værdisat lavt og fordi naturbeslaglæggelse ikke er værdisat.

Generelt viser konsekvens-tilgangen højere resultater. Dette skyldes, at indirekte land use changes er inkluderet. Dette medfører væsentlige påvirkninger på bl.a. naturbeslaglæggelse (biodiversitet).

TABEL. FORSKLARING AF VÆRDISATTE RESULTATER VED ANVENDELSE AF FORSKELLIGE METODER. INTERVALLERNE REPRÆSENTERER FORSKELLIGE VERSIONER AF VÆRDISÆTNINGSMETODERNE.

Metode	Result Million EUR	Forklaring
Stepwise		
- Konsekvens LCA	5850	Høje bidrag: Drivhusgasser, ammoniak og naturbeslaglæggelse Lave bidrag: Ingen
- Attributional LCA	4984	Høje bidrag: Drivhusgasser, ammoniak Lave bidrag: Naturbeslaglæggelse
Miljøstyrelsens anbefalede værdisætning		
- Konsekvens LCA	2900-4270	Høje bidrag: Ammoniak Lave bidrag: Drivhusgasser (naturbeslaglæggelse ikke værdisat)
- Attributional LCA	2240-3710	
Trucost		
- Konsekvens LCA	1840-1910	Høje bidrag: Drivhusgasser Lave bidrag: Ammoniak (naturbeslaglæggelse ikke værdisat)
- Attributional LCA	2370-2430	

Robusthed af resultater

Overordnet anses data, antagelser og resultater i fysiske enheder at have en høj grad af konsistens og komplethed. Der er relativt store forskelle i resultater fremkommet ved konsekvens- og attributional-tilgangen. Men da de to tilgange søger at svare på forskellige spørgsmål er dette forventeligt. De væsentligste usikkerheder er relateret til usikkerheder i data for modellering af indirekte land use changes og emissionsmodeller (enterisk fermentering of markemissioner). For værdisætning ses generelt større usikkerheder og resultater er meget afhængige af valg af metode.

Konklusion

Denne Environmental Profit and Loss Account (E P&L) er den første af sin slags indenfor fødevaresektoren. Resultaterne er beregnet på baggrund af omfattende dataindsamling og livscyklusvurderinger. Resultaterne viser, at både værdien (Profit) og miljøpåvirkningen (Loss) fra Arla Foods produktion og efterfølgende distribution og forbrug af produkter er høj. E P&L opgørelsen giver et bredt og dybt indblik i miljøpåvirkningerne fra livscyklussen af Arla Foods produktportefølje samt de underliggende bidrag. Analysen giver således et godt grundlag for en mere fyldestgørende rapportering af virksomhedens bæredygtighed, og for identificering af muligheder for forbedring af miljøperformance.

E P&L opgørelsen er blevet udarbejdet ved anvendelse af to forskellige tilgange til modellering i LCA: konsekvens- og attributional modellering. Resultaterne for hver tilgang kan bruges til forskellige formål. Konsekvens-tilgangen bør anvendes, når information fra E P&L opgørelsen påtænkes at blive anvendt til beslutningsstøtte (direkte eller indirekte), og når viden om konsekvenser af forskellige handlinger søges. Attributional-tilgangen er relevant, når resultater skal rapporteres i henhold til en normativ reference; i nærværende tilfælde the International Dairy Federation’s guidelines for livscyklusvurdering.

Resultater ved værdisætning af miljøpåvirkninger viste sig, at være meget afhængig af metodevalg. Fremadrettet efterspørges mere forskning og mere videnskabelig konsensus i, hvorledes miljøpåvirkninger skal værdisættes.

Summary and conclusion

Introduction

To document the total life cycle environmental impact of their product portfolio, Arla Foods is conducting an Environmental Profit and Loss Account (E P&L). The E P&L expresses Arla Foods' environmental impacts in monetary units, in addition to the underlying physical units. Arla Foods intends to use the results to evaluate their environmental strategy 2020 in order to assure that its focus is put on priority areas. Furthermore, the findings are intended to be used in various communications and it is an important step towards showing that Arla takes its environmental commitment seriously and takes responsibility for the whole value chain.

The unit of analysis is the sum of all Arla's activities in 2014. Hence, the E P&L includes all environmental life cycle impacts from cradle to grave of the sum of all Arla's products for the financial year 2014. The included product system is illustrated in the figure below.

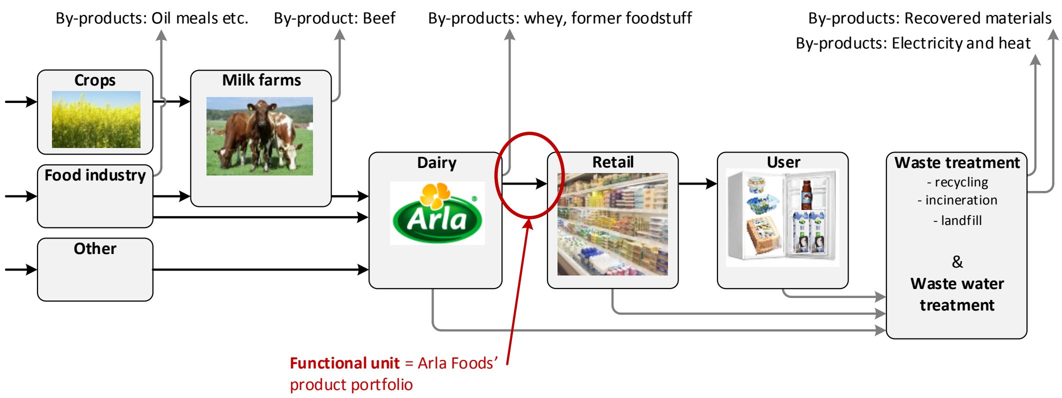


FIGURE. OVERVIEW OF THE PRODUCT SYSTEM RELATED TO ARLA FOODS' PRODUCTS. THE GREY ARROWS REPRESENT BY-PRODUCTS AND WASTE FLOWS.

Arla Foods' product portfolio in 2014 includes 7.68 million tonne dairy products and 1.32 million tonne by-products (whey and former food products that are sold as animal feed). Out of the 7.68 million tonne dairy products, 5.55 million tonne are fresh dairy products (milk, yogurts, cream etc.) and 0.68 million tonne is cheese. The rest is whey/milk powder, butter and spreads, and non-milk based products (mainly fruit juice).

The E P&L includes activities for the whole company, including the daughter companies Arla Foods Ingredients, Rynkeby and Cocio, but excluding joint ventures. All Arla foods production sites, distribution centres and administrative units (99 sites in 12 countries) are part of the study. Production and use of raw materials, energy carriers, packaging and transport (inbound and outbound) are included, as well as treatment and utilization of by-products and wastes. In addition, products and services not directly used in production, such as computers, furniture and travelling are covered. The downstream parts of the life cycles (retail and consumers) are also included.

Methods

In order to calculate the life cycle emissions, life cycle assessment (LCA) is used. LCA is a method where all emissions and resources from all activities in a life cycle product system are added. Based on these life cycle emissions and resources, the life cycle impact results can be calculated. Results are presented at mid-point in physical units as well as at end-point in monetary units. Mid-point results include e.g. global warming, respiratory effects, nature occupation (biodiversity), and end-point results are calculated as the sum of impacts on human health, ecosystems and resources in monetary unit.

When calculating the life cycle emissions and resources, two different approaches for LCA are commonly used: the consequential approach and the attributional approach. The results are presented using both approaches. The **box** briefly explains the different focus of the two approaches. The consequential approach follows the requirements and guidelines in (ISO 2006; Weidema 2003; Weidema et al. 2009) and the attributional approach follows the requirements in (IDF 2010).

Two LCA methods, two sets of results, answers to two different questions

Consequential LCA gives an answer on the question: "*what is the impact of a choice*?" This choice could be to buy or produce a product, or to implement an improvement option. Consequential LCA is relevant when Arla wants to know the impacts of their actions.

Attributional LCA gives an answer on the question: "*what are the impacts from that part of the life cycle that it has been decided to include based on the normative allocation and cut-off rules?*" Attributional LCA is relevant when Arla wants to report their impacts according to consensus-based guidelines/standards.

BOX. CONSEQUENTIAL ANDATTRIBUTIONAL LCA – TWO WAYS OF MODELLING A PRODUCT SYSTEM IN LCA.

The inventory of the life cycle of Arla Foods' products takes into account that the use of land for animal feed contributes to the pressure on lands and thereby to transformation of unproductive (natural) land into productive land. This most often take place in other regions of the world than where the actual animal feed is grown. For example, the use of one hectare land in Denmark in one year will have effects on deforestation in e.g. Brazil. The transformation of land from forest to agricultural land implies a change in the biodiversity hosted on the land as well as a change in the carbon stock of the land, which in turn leads to CO_2 emissions. This contribution to biodiversity impacts and CO_2 emissions is referred to as indirect land use changes (iLUC). Since it is not common to including indirect land use changes in attributional LCA, iLUC is only included in the consequential results.

When calculating the mid-point and end-point results, this is based on the Stepwise method (Weidema et al. 2007; Weidema 2009). The Stepwise method uses commonly acknowledged methods for calculating mid-points, e.g. global warming is calculated using IPCC's global warming potential (GWP100). The valuation step in LCA is less commonly applied, and therefore there is no generally acknowledged methods for this step. Besides using the Stepwise method for valuation, this is also carried out by using the recommended guidelines by the Danish EPA and the method developed by Trucost, which was used in previous studies published by the Danish EPA.

Main findings

By using the valuation in the Stepwise method, the following impact categories related to the life cycle of Arla Foods' product portfolio in 2014 were identified as the most significant:

- Global Warming (CO_2, CH_4, N_2O)
- Respiratory inorganics (air emissions: particles, ammonia, NO_x, SO_2)
- Nature occupation (biodiversity)

The attributional results showed that terrestrial eutrophication were also important (though less than global warming and respiratory inorganics).

The importance of the impacts listed above was confirmed by other weighting methods for life cycle impact assessment (LCIA) as well as other valuation methods. The other LCIA methods point at the use of non-renewable energy as another important impact category. In addition to the impact categories mentioned above, mid-point results are also shown for water use and land occupation. These impacts are not monetarised in the valuation step; land occupation is an intermediate flow linking land use and land use changes (only land use changes are monetarised), and water use is not included in the monetarisation in Stepwise.

Results presented as mid-point impacts in physical unit
The calculated mid-point are summarised in the table below.

TABLE: IMPACT CATEGORIES AT MID-POINT. RESULTS ARE SHOWN FOR TWO MODELLING ASSUMPTIONS IN THE LIFE CYCLE INVENTORY: CONSEQUENTIAL (CAUSE-EFFECT BASED) AND ATTRIBUTIONAL (NORMATIVE/RULE BASED).

		Indicator results	
Impact category	**Unit**	**Consequential**	**Attributional**
Stepwise. These impacts are monetarised			
Global warming	million tonne CO_2-eq	20.2	26.6
Respiratory inorganics	tonne $PM_{2.5}$-eq	23,551	19,018
Respiratory organics	million pers*ppm*h	14	22
Nature occupation	PDF*ha*year	544,000	-26,000
Acidification	ha UES	385,000	287,000
Eutrophication, terrestrial	ha UES	1,626,000	1,139,000
Eutrophication, aquatic	tonne NO_3-eq	540,000	376,000
Photochemical ozone, vegetat.	million ha*ppm*hours	14	21
Human toxicity, carcinogens	tonne C_2H_3Cl-eq	232,000	144,000
Human toxicity, non-carc.	tonne C_2H_3Cl-eq	129,000	94,000
Ecotoxicity, aquatic	million tonne TEG-eq w	492	404
Ecotoxicity, terrestrial	million tonne TEG-eq s	63	50
Ionizing radiation	million Bq C-14-eq	54,000	188,000
Non-renewable energy	TJ primary	136,000	164,000
Mineral extraction	TJ extra	740	618
Additional impacts. These impacts are not monetarised			
Land occupation	million ha	-3.63	2.74
Water use, blue water footprint	million m^3	194	293

The majority of the impacts are related to activities in agriculture: animal and feed production. Hence, the contribution analysis showed that 59% (consequential) and 62% (attributional) of the total life cycle GHG emissions related to Arla Foods' product portfolio were related to the production of raw milk. Milk production was also dominating for the other impact categories – except nature occupation in the attributional results, which show a small negative result. The reason for this is that the attributional results do not include indirect land use changes, which is where the majority of the biodiversity impact is occurring. Attributional results only include the direct land use effects. Since extensive pastures used for milk cattle host more biodiversity than the alternative use of such lands, the direct land use effects become negative.

Another negative result that deserves some comments is land occupation in the consequential results. The reason why this is negative is that the consequential modelling includes all the land uses relating to milk production and subtracts all the land uses related to the by-product of milk production, i.e. the beef. Hence, the negative result involves a positive contribution in the milk and feed producing countries and a negative contribution in Brazil, which is regarded as the marginal supplier of beef. The reason why the net land use becomes negative is that the substituted beef system in Brazil is very extensive, i.e. the animal density on the affected grasslands is very low. It should also be noted that the total impact on nature occupation (biodiversity) is not negative. This is because the substituted occupation of grassland does not have as high an impact on nature occupation as occupation of arable land.

The following two figures give a detailed overview of the contributions to GHG emissions from the different life cycle stages. The first figure provides the results of the consequential modelling and second figure provide the results of the attributional modelling.

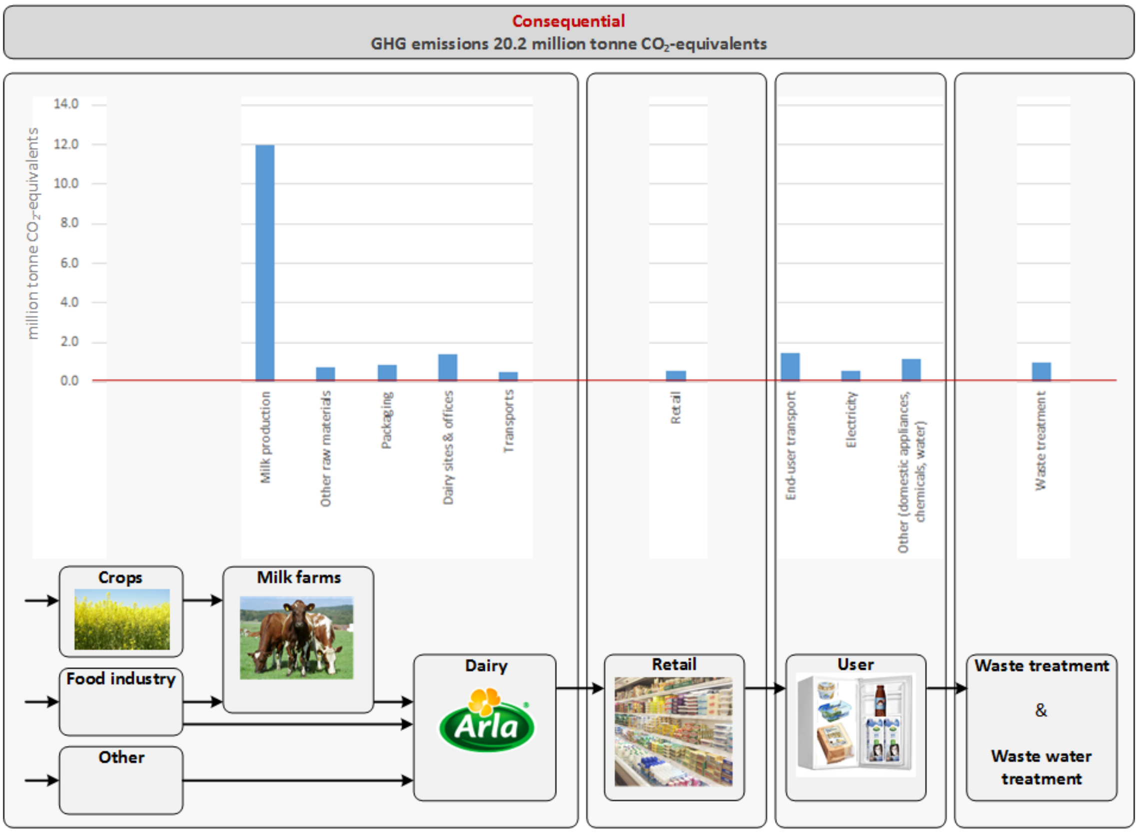


FIGURE. ILLUSTRATION OF THE CONTRIBUTION TO GHG EMISSIONS FROM DIFFERENT LIFE CYCLE STAGES. **CONSEQUENTIAL RESULTS**.

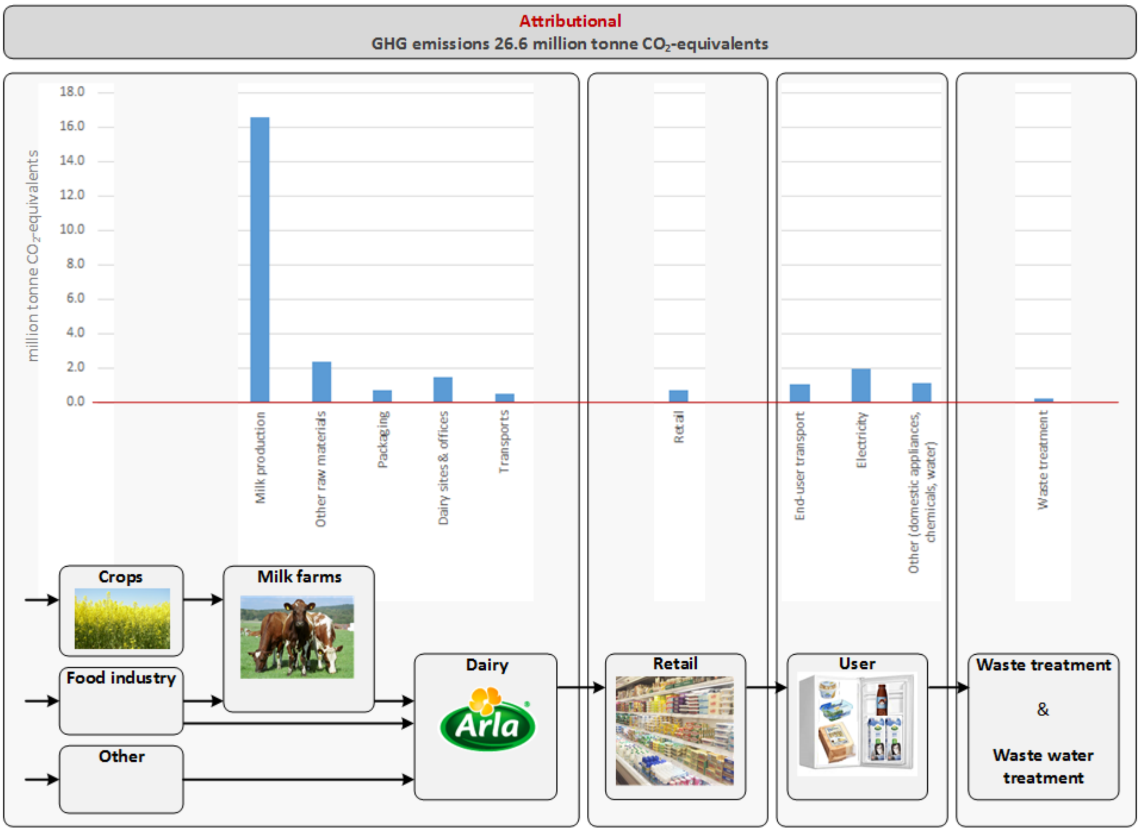


FIGURE. ILLUSTRATION OF THE CONTRIBUTION TO GHG EMISSIONS FROM DIFFERENT LIFE CYCLE STAGES. **ATTRIBUTIONAL RESULTS**.

Results presented as monetarised impacts
The monetarised results express the damage caused by externalities related to Arla Foods' product portfolio. The monetarised impacts, i.e. the investigated externalities, can be compared to Arla Foods' revenue at 10,600 million EUR2014, which indicate the created value.

When monetarising the impacts, the consequential and attributional approaches show a contribution at 1840-5850 and 2240-4980 million EUR, respectively. The intervals represent results obtained using different valuation methods. It appears that the results highly depend on the choice of valuation method. In the table below, the monetarised results obtained using the different valuation methods are explained.

The conclusion is that Stepwise shows the highest results. This is because GHG emissions, ammonia and nature occupation are associated with high costs. The valuation method recommended by the Danish EPA shows lower results than Stepwise because GHG emissions are associated with low costs (based on CO_2 quota prices) and because nature occupation is not valuated. Trucost's method shows lower results than Stepwise because ammonia is associated with low costs and because nature occupation is not valuated.

Generally, the consequential approach shows higher results than the attributional approach because indirect land use changes are included. This causes significant impacts on e.g. nature occupation (biodiversity).

TABLE. EXPLANATION OF MONETARISED RESULTS OBTAINED BY USING DIFFERENT METHODS. THE INTERVALS REPRESENT DIFFERENT VERSIONS OF THE VALUATION METHODS.

Method	Results Million EUR	Explanation
Stepwise		
- Consequential LCA	5850	High contribution: GHG emissions, ammonia and nature occupation Low contribution: None
- Attributional LCA	4984	High contribution: GHG emissions, ammonia Low contribution: Nature occupation
Valuation recommended by the Danish EPA		
- Consequential LCA	2900-4270	High contribution: Ammonia Low contribution: GHG emissions (nature occupation is not valuated)
- Attributional LCA	2240-3710	
Trucost		
- Consequential LCA	1840-1910	High contribution: GHG emissions Low contribution: Ammonia (nature occupation is not valuated)
- Attributional LCA	2370-2430	

Robustness of results

Overall, the data, modelling assumptions and impact assessment for results in physical unit, are regarded as having a high level of consistency and completeness. Relatively large differences are seen for results obtained using the consequential and attributional approaches. However, since the two approaches are used for answering different questions, this is expected. The major uncertainties are related to uncertainties in data with regard to indirect land use changes and emission models (enteric fermentation and field emissions). For the valuation of the impacts, larger uncertainties and dependencies of choice of methods are seen.

Conclusion and outlook

This Environmental Profit and Loss Account (E P&L) is the first of its kind for the food sector. The results are calculated based on comprehensive data collection and life cycle assessments. The results show that both the value (Profit) and the impacts (Loss) of Arla Foods production and subsequent distribution and consumption of their products are high. The E P&L account gives a broad and deep insight in the impacts from the full life cycle of Arla Foods product portfolio and the underlying contributions. Hence, it provides a good basis for more comprehensive sustainability reporting and for identifying options for improving the performance and reducing the impact.

The contribution analysis of the causes of the overall monetarised impact showed that a very large share can be explained by few emissions, few impact categories and few life cycle stages. Hence, the E P&L can help focussing on the most important impacts. Furthermore, the account can be used as a baseline to which different improvement options are evaluated.

The E P&L account has been compiled using two different approaches: consequential and attributional. The results from each approach can be used for different purposes. The consequential approach should be used, when information from the E P&L is intended for decision support (directly or indirectly) and when knowledge of the impact of different actions is sought. The attributional results are relevant when results need to be reported according to a common and normative reference; here the International Dairy Federation Guideline on life cycle assessment.

The results for monetarised impacts showed to be highly dependent on the choice of valuation method. This points at the need for more research and more scientific consensus of how to monetarise environmental impacts.

Glossary and acronyms

Glossary

BAHY	Biodiversity Adjusted Hectare Year. Equivalent to the Potentially Disappeared Fraction of species for 10,000 m^2*year.
Ecological footprint	The "biologically productive land and water" that a population requires to produce the resources it consumes and to absorb part of the waste generated by fossil and nuclear fuel consumption.
E P&L	Environmental Profit and Loss account. Product portfolio environmental life cycle assessment with monetary valuation of impacts. An E P&L is generally equivalent to what the European Commission calls an Organisation Environmental Footprint (OEF) (European Commissions 2013), and what the UNEP/SETAC Life Cycle Initiative calls an Organizational Life Cycle Assessment (OLCA) (UNEP/SETAC 2015). The only difference is that E P&L uses monetarisation as weighting in the life cycle impact assessment, which is commonly not done in LCAs and OEF/OLCA.
Monetarisation	Monetary valuation of the cost (and benefits) of environmental impacts (externalities).
Natural capital	Stock of natural assets that are useful for future (human) production and/or consumption. Provins et al. (2015) specifies this in terms of "*the elements of nature that directly and indirectly produce value or benefits to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions*". Natural capital thus covers abiotic natural resources as well as ecosystem resources that provide us with 'ecosystem services'.
NCA	Natural capital account. To be consistent with the definition of natural capital, NCA should only include impacts and dependencies around 'Natural capital' and not 'other environmental impacts'.
NFC	Not from concentrate.
Natural capital valuation	Method of monetarising the impacts that business activities have on natural capital (resources and ecosystem services).

Acronyms

BAHY	Biodiversity-Adjusted Hectare Year
CHP	Combined heat and power plant
CO_2	Carbon dioxide
DALY	Disability Adjusted Life Year
dLUC	Direct Land Use Change
DM	Dry matter
E P&L	Environmental Profit and Loss Account
GHG	Greenhouse Gas
iLUC	Indirect Land Use Change
LCA	Life cycle assessment
LUC	Land use change
NCA	Natural Capital Account
NO_x	Nitrous Oxides
NMVOCs	Non-Methane Volatile Organic Compounds
PDF	Potential Disappeared Fraction
Ph. Chem.	Photochemical
PM10	Particles with an aerodynamic diameter <10µm
PM2.5	Particles with an aerodynamic diameter <2.5µm
QALY	Quality-Adjusted Life Year
Veg.	Vegetation
VOCs	Volatile Organic Compounds
VOLY	Value of a Life Year
VPF	Value of a Prevented Fatality
ww	Wet weight

Countries and regions

BE	Belgium
BR	Brazil
CH	Switzerland
CN	China
CZ	Czech Republic
DE	Germany
DK	Denmark
EU	European Union
EU27	European Union, 27 countries
FI	Finland
FR	France
GLO	Global
ID	Indonesia
MX	Mexico
MY	Malaysia
PL	Poland
RER	Refers to the region of Europe
SE	Sweden
UK	United Kingdom
US	United States of America

1. Introduction

To document the total environmental impact of Arla Foods, Arla is conducting an Environmental Profit and Loss Account (E P&L), partly founded by the Danish Environmental protecting Agency (Miljøstyrelsen). The E P&L expresses Arla Foods' environmental impacts in monetary units, in addition to the underlying physical units. The results will be used to evaluate Arla's environmental strategy 2020 in order to assure that its focus is put on priority areas. The E P&L will also be used in various communications and it is an important step towards showing that Arla takes its environmental commitment seriously and takes responsibility for the whole value chain. The Danish government wants to increase focus on E P&L studies as a way for companies to report their environmental impact. Today, only a few E P&Ls have been conducted. Arla Foods will be the first food company conducting such a study.

Environmental Profit and Loss Accounting (E P&L) is often used as an expanded version of a traditional economic accounting (national or corporate) where environmental externalities are monetarised. Since the costs of externalities are not included in traditional economic accounts, the aim of the valuation/monetarisation is to give a better picture of the "true" costs. The first acknowledged corporate E P&L was published by PUMA with their '*PUMA's Environmental Profit and Loss Account for the year ended 31 December 2010*' (PUMA 2011). The scope of the Arla E P&L project is similar.

The unit of analysis is the sum of all Arla's activities in 2014. Hence, the E P&L includes all environmental life cycle impacts from cradle to grave of the sum of all Arla's products for the financial year 2014. This involves emissions and resources involved in the production of raw milk at farm level, transportation, processing in Arla's manufacturing facilities, distribution, retail, consumption and disposal.

The E P&L includes activities for the whole company, including the daughter companies Arla Foods Ingredients, Rynkeby and Cocio, but excluding joint ventures. All Arla foods production sites, distribution centres and administrative units (99 sites in 12 countries) are part of the study. Production and use of raw materials, energy carriers, packaging and transport (inbound and outbound) are included, as well as treatment and utilization of by-products and wastes. In addition, products and services not directly used in production, such as computers, furniture and travelling are covered. The downstream parts of the life cycles (retail and consumers) are also included.

To obtain a comprehensive understanding of the full environmental impact of Arla Foods, a broad range of environmental impact categories are included in the impact assessment. This includes Global warming, Eutrophication, Acidification, Other air pollutants (e.g. particulate matter), Biodiversity, Energy use, Water use and Resource depletion. The impacts are monetarised so that the results can be shown in monetary units and therefore more easily compared.

2. Definition and scope of the Arla Foods E P&L

2.1 The E P&L method – guidelines and standard

The current study is a so-called environmental profit and loss account (E P&L). In 2011, PUMA launched the first acknowledged E P&L (PUMA 2011), a practice that was followed by several others, including Novo Nordisk (Høst-madsen et al. 2014), the Danish Fashion Industry (Høst-Madsen et al. 2014) and an E P&L on the Sollentuna municipality in Sweden (Wendin et al. 2014).

An E P&L can be described as "a means of placing a monetary value on the environmental impacts along the entire supply chain of a given business." (PUMA 2011, p 2). A life cycle approach is used to cover the entire supply chain. Generally, 'environmental impact' is defined broadly, not intended to exclude any impact. The intention is to complement the company's normal Profit & Loss account (the financial statement of the pecuniary income and expenditure) with an account of the monetarised external benefits and costs related to the life cycle of the product portfolio of the company (Weidema 2015). Since the costs of externalities are not included in traditional economic accounts, the aim of the valuation/monetarisation is to give a better picture of the "true" costs. An E P&L can thus be defined as a "product portfolio environmental life cycle assessment with monetary valuation of impacts". An E P&L is generally equivalent to what the European Commission calls an Organisation Environmental Footprint (OEF) (European Commissions 2013), and what the UNEP/SETAC Life Cycle Initiative calls an Organizational Life Cycle Assessment (OLCA) (UNEP/SETAC 2015). The only difference is that E P&L uses monetarisation as weighting in the life cycle impact assessment, which is commonly not done in LCAs and OEF/OLCA.

In the guide to NCA (Natural Capital Accounting) published by the European Commission's Business and Biodiversity Platform (Spurgeon 2014), E P&L is mentioned as one possible approach. There are several on-going initiatives developing frameworks for NCAs:

- the Natural Capital Accounting workstream (European Commissions Business and Biodiversity Platform 2014)
- the UK-based Natural Capital Committee (NCC) working with a Consortium of eftec, RSPB and PwC. They have published an overview, a methodology and guidelines to conduct Corporate NCAs (CNCA) (Natural Capital Committee 2014).

We do not apply the term NCA to the current study, since in our understanding, following the definition of "natural capital" literally, NCA only covers a relatively small part of what we normally associate with environmental impacts.

The concept of "capital" is limited to the assets that have instrumental value for (future) production and consumption. This means that intrinsic (non-use) values of e.g. biodiversity would not be included in NCA. Furthermore, "Natural Capital" can per definition not cover the value of non-natural capital, whether intrinsic (human wellbeing and cultural heritage) or instrumental (man-made and human capital) (Weidema 2015).

Natural Capital can be defined as a "stock of natural assets that are useful for future (human) production and/or consumption." Provins et al. (2015) specifies this further as "*the elements of nature that directly and indirectly produce value or benefits to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and* *functions*" (Provins et al. 2015, p 4). The natural capital and flows of services to produce these benefits are illustrated in the figure below.

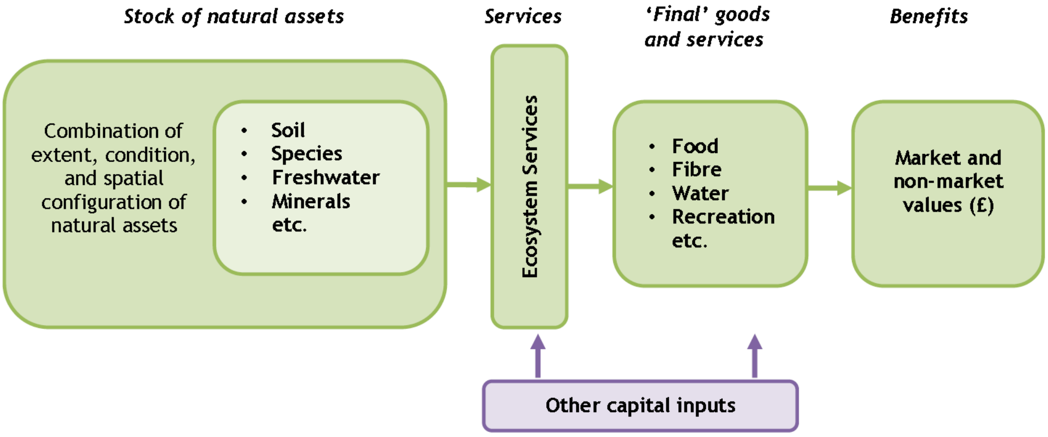


FIGURE 2.1, ILLUSTRATION OF HOW FLOWS OF ECOSYSTEM SERVICES CONTRIBUTES PROVIDING THE BASIS FOR BENEFITS TO PEOPLE. THE FIGURE IS OBTAINED FROM PROVINS ET AL. (2015, P 4).

A natural capital account (NCA) can then focus on the stocks of natural assets or the impacts on the stocks. An example of focussing on stocks could be an account of biodiversity hosted on the lands owned by a company, e.g. when palm oil industry has nature conservation reserves. An example of an account focussing on the impact on natural capital could be the impact on the recreation value by having nature conservation reserves.

2.2 Overview of Arla Foods and its supply chain

Arla Foods produces a number of different dairy products such as:

- Milk
- Cheese
- Butter and spreads
- Yogurt
- Milk powder
- Whey based products
- Fruit juice (Rynkeby)
- Chocolate milk (Cocio)

Furthermore, Arla Foods sells whey and 'former foodstuff'; both are sold as animal feed.

The life cycle of Arla Foods' products involves the following main stages: Production of raw materials (mainly milk), Arla Foods' own production (dairy processing), retail, use, and end-of-life. The product system is schematised in **Figure 2.2** below.

The main raw material for Arla Foods production is milk from farm. However, a large number of other raw materials are also used; e.g. vegetable oils, fruits/fruit preparations, sugars, cultures, coffee, cereals, starches, and several functional ingredients.

Besides the inputs of raw materials, Arla Foods also uses energy, packaging material, transport services, overhead material (paper etc.), various equipment and machinery, buildings, and various services (marketing, laboratory, tele- and data communication, insurance, legal, banking, waste management, cleaning, etc.).

The production of the inputs to Arla Foods described above is generally categorised as upstream product chain (except waste treatment), while every activity that happens after the products leave the factory of Arla Foods are categorised as downstream. Downstream activities include e.g. retail, use of Arla's products, and waste treatment.

Several of the upstream and downstream activities, as well as Arla's own production, are associated with the production of by-products, e.g. beef (live animals from milk farms, i.e. surplus calves and culled milking cows), vegetable oil from soy meal production, protein meals from rapeseed, palm and sunflower oil production, whey from cheese and caseinate production, recovered energy from waste incineration and recovered materials from recycling of packaging materials. These by-products are illustrated in **Figure 2.2** below.

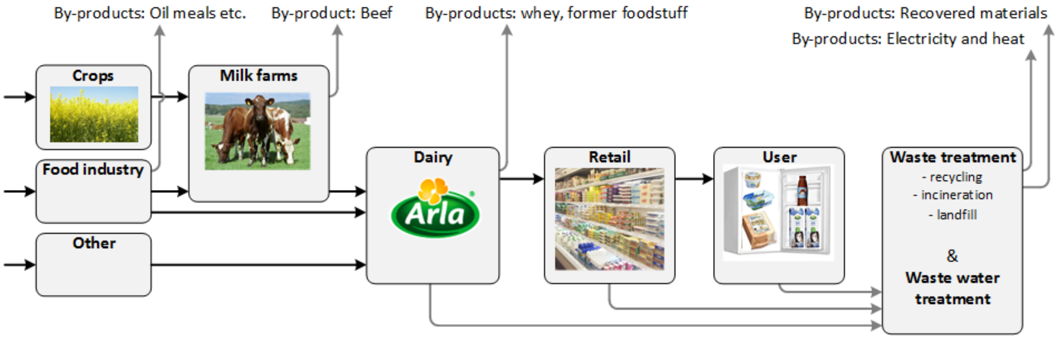


FIGURE 2.2, OVERVIEW OF THE PRODUCT SYSTEM RELATED TO ARLA FOODS' PRODUCTION. THE GREY ARROWS REPRESENT BY-PRODUCTS AND WASTE FLOWS.

In 2014, 99 companies collaborated in the Arla supply chain:

- 19 distribution companies
- 75 food-processing companies producing fresh dairy products, butter and spread, cheese, powder, non-milk based products (mainly fruit juice), former foodstuff (animal feed) and whey.
- 5 administration companies.

The companies are located in 12 different countries: Denmark, Argentina, Germany, the Netherlands, Poland, Mexico, Saudi Arabia, Canada, the USA, Finland, Sweden, and the UK.

2.3 Functional unit and reference flows

The functional unit of the E P&L is defined as Arla Foods' entire production in 2014, including upstream and downstream activities. The calculation has a corporate focus rather than the product focus, which is used in life cycle assessment (LCA). However, the only difference between a corporate LCA and a product LCA is that the corporate LCA is a sum of several product LCAs adding up the company's product portfolio. Arla's product portfolio in 2014 is given in **Table 2.1**.

It should be noted that some of the products in **Table 2.1** are by-products. It has been chosen to include the full life cycle of the main products supplied by Arla Foods, while only the cradle-to-gate stages are included for by-products. The obvious and easy-to-understand reason for this choice is that it is natural to include the outbound transport, retail, use and disposal stages of the main products, e.g. milk and cheese, because these stages are part of milk's and cheese's life cycles. However, for by-products, such as animal feed and energy, it would make little sense to include the use stage (animal use of feed and uses of energy) because these activities can be defined as being part of other products' life cycles. The more theoretical arguments for excluding the downstream stages of by-products are given in the following.

A by-product can be defined as a product for which the production volume is fully determined by the demand for the other products supplied by Arla. The downstream fate of by-products are possible intermediate treatments followed by product substitutions. This means that a change in the output of a by-product will not affect the amount of the use of this type of product. An example is by-products sold as animal feed, e.g. whey. A change in demand for animal feed will not affect the output of whey – since this is determined by the demand for cheese. Furthermore, a change in demand for cheese, and thereby the output of whey, will not induce downstream changes in the overall use of animal feed (which is determined by the demand for meat and dairy products). Therefore, the use and end-of-life stages of by-products are not included in the product system for Arla Foods.

Whey and former foodstuff are both by-products for which the marginal use is as animal feed. The term 'marginal use' refers to the use of an additional output of the by-products. A large share of whey is processed into a high value protein product for human intake. Obviously, the production of this high value product will be maximised, and only the excess whey will be used as animal feed. As long as not all whey is utilised for high value protein products, the marginal use of whey will be animal feed.

It can also be discussed whether butter is a by-product. Since butter is largely substitutable with vegetable oils[1], and since it only constitutes a rather small part of the overall revenue of milk and cheese dairy production, it can be argued that this is a by-product. However, the production of spreads is not produced in a fixed ratio with milk and cheese, because (i) the relative output of spreads to milk and cheese can be varied by changing the fat content of e.g. cheese and yogurts, and (ii) the proportion of vegetable oil in the spreads can be changed. Therefore, butter and spread are regarded as main products and not by-products, and hence the use and end-of-life stages are included.

TABLE 2.1: ARLA'S PRODUCT PORTFOLIO IN 2014. THE INCLUDED LIFE CYCLE STAGES IN THE FUNCTIONAL UNIT OF EACH PRODUCT TYPE ARE INDICATED.

Arla products	Amount (tonne wet weight)	Share	Type of product	Life cycle stages included in functional unit
Fresh dairy products (milk, yogurts, cream…)	5,551,000	62%	Main product	Full
Whey for animal feed	1,232,000	14%	By-product	Cradle-to-gate
Cheese	680,000	8%	Main product	Full
Powder	501,000	6%	Main product	Full
Whey powder	493,000	5%	Main product	Full
Butter and Spread	274,000	3%	Main product	Full
Non milk based products (mainly fruit juice)	181,000	2%	Main product	Full
Former Foodstuff (animal feed)	87,000	1%	By-product	Cradle-to-gate
Total main products	**7,680,000**	**85%**	**Main product**	**Full**
Total by-products	**1,319,000**	**15%**	**By-product**	**Cradle-to-gate**
Total	**8,999,000**	**100%**		

[1] Butter is mixed with vegetable oil in many proportions in different spreads.

3. Methodology and scope of the study

When modelling life cycle product systems, a number of important methodological choices need to be made. Some of the most important modelling assumptions concern the modelling of by-products and market mixes of affected products. This is further described in the next sections.

3.1 Modelling approaches in life cycle inventory

Two basic sets of assumptions exist for modelling in life cycle inventory; consequential and attributional modelling (Sonneman and Vigon 2011).

Consequential modelling is a cause-effect based approach to the definition of system boundaries in LCA, and it is characterised by the modelling of by-products using substitution and by including only unconstrained suppliers in the market mixes. Consequential modelling is used when the study is aimed for decision support and when results are aimed at representing a change in demand for the product at focus in the LCA. For the current study, this would mean that the results would represent the difference between the current situation (Arla Foods production in 2014) with a situation where there was no demand for Arla Foods' products in 2014.

Attributional modelling is a normative approach to the definition of system boundaries in LCA, and it is characterised by the modelling of by-products using allocation and by including all suppliers in the market mixes (both constrained and unconstrained). Attributional modelling is used when a set of normative rules are available to delimit the activities attributed to the product, either by economic or physical flows.

Consequential and attributional LCAs give answers to different questions. Consequential LCA gives an answer on the question: "*what is the impact of a choice?*" This choice could be to buying or producing a product, or to implementing an improvement option. Consequential LCA is relevant when Arla wants to know the impacts of their actions. Attributional LCA gives an answer on the question: "*what are the impacts from that part of the life cycle that it has been decided to include based on the normative allocation and cut-off rules?*" Attributional LCA is relevant when Arla wants to report their impacts according to consensus based guidelines/standards, e.g. the International Dairy Federation Guideline on life cycle assessment (IDF 2010).

The two approaches are comprehensively described in Schmidt and Dalgaard (2012a), Weidema (2003) and Weidema et al. (2009).

When substitution is applied, it is important to distinguish between determining (reference) products and by-products. Reference products are characterised by being the ones for which the demand determine the production volume of the activity, while by-products are produced regardless of the demand. An example of a determining product is milk from a milk farm, where a by-product is the beef from the surplus calves and culled cows. For allocation, the distinction between reference products and by-products is not needed.

There are pros and cons of both consequential and attributional modelling. The most important ones are listed in **Table 3.1.**

TABLE 3.1: PROS AND CONS OF CONSEQUENTIAL AND ATTRIBUTIONAL MODELLING.

Consequential modelling	Attributional modelling
Pros	
• Follows ISO 14044 on allocation • Based on scientific criteria. • Mass balances are maintained. • Processes can be verified by experts. • Relatively simple to apply consistent modelling of by-products through the product system.	• Seemingly easy: Since the approach is normative, ad hoc choices can be made to exclude complex issues. • Most industry specific LCA and GHG guidelines are based on attributional modelling, e.g. the IDF guideline for carbon Footprinting (IDF: International Dairy Federation).
Cons	
• Hard to Communicate: Since constrained suppliers are excluded, the directly economically connected product chain is not always followed.	• Complicated (or impossible) to consistently apply same allocation approach throughout a product system. • Allocated systems do not exist in reality – experts cannot recognise allocated product systems. • Goes against ISO 14044 on allocation. • Mass, substance, energy, and other balances are not maintained when allocating. • May lead to misleading results. • Hard to communicate: Since allocated product systems do not exist in reality, the modelled system can be difficult to communicate.

To illustrate what happens with a product system when by-products are either modelled using substitution or allocation, the two approaches have been applied to Arla Foods product system (**Figure 2.2**) in the following two figures.

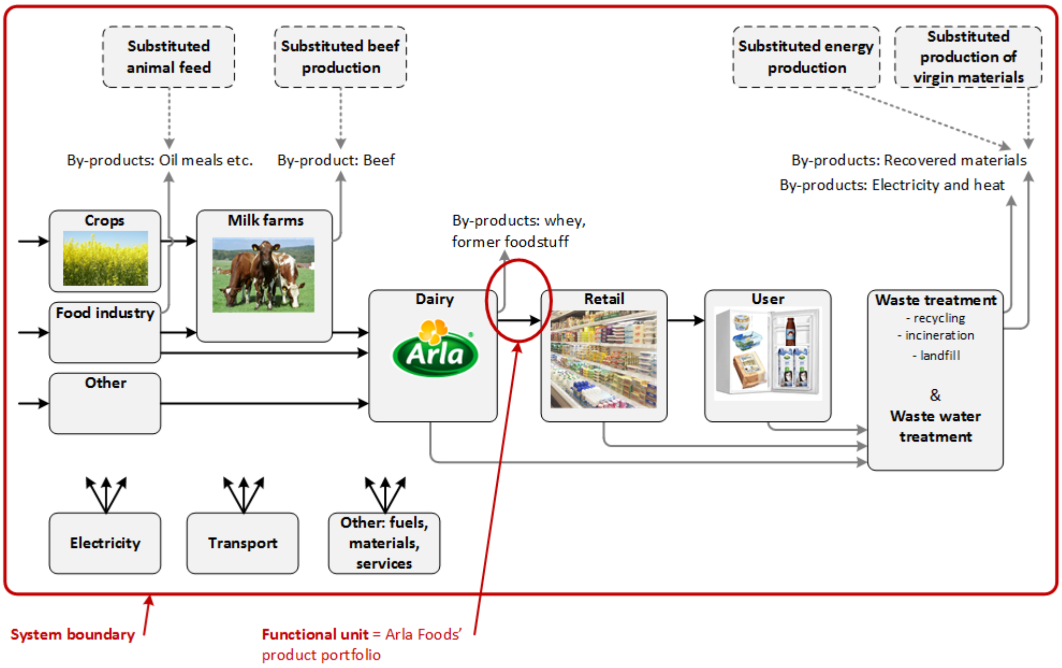


FIGURE 3.1, ARLA FOODS' PRODUCT SYSTEM WHEN BY-PRODUCTS ARE MODELLED USING SUBSTITUTION (CONSEQUENTIAL MODELLING).

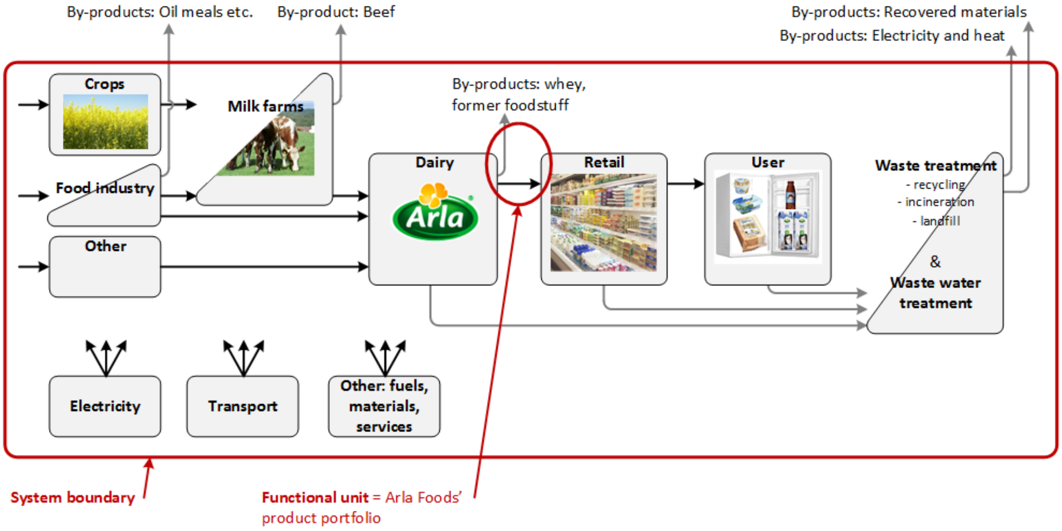


FIGURE 3.2, ARLA FOODS' PRODUCT SYSTEM WHEN BY-PRODUCTS ARE MODELLED USING ALLOCATION (ATTRIBUTIONAL MODELLING). THE MISSING PARTS OF THE ACTIVITIES ARE ALLOCATED TO BY-PRODUCTS NOT BELONGING TO ARLA FOODS PRODUCT SYSTEM, AND ARE THEREFORE EXCLUDED.

It appears from **Figure 3.1** and **Figure 3.2** that the allocated system does not include the substituted systems and that the allocated system only partially includes the activities involved in the production of the upstream and downstream products of Arla Foods.

In the current study, the results have been calculated using both of the above-mentioned approaches. **Table 3.2** summarises the main differences in the modelling of the two approaches. The attributional approach follow the requirements in the International Dairy Federation Guideline on life cycle assessment (IDF 2010).

TABLE 3.2: DESCRIPTION OF THE APPROACH TO MODELLING WHERE THERE ARE SIGNIFICANT DIFFERENCES IN THE CONSEQUENTIAL AND ATTRIBUTIONAL APPROACHES.

Activity/product group	Consequential modelling	Attributional modelling
Agriculture: plant cultivation		
Fertiliser and associated emissions	Use of fertiliser is modelled as 100% mineral fertiliser. Manure is regarded as constrained by the demand for animal products. Manure N is converted to equivalents of mineral fertiliser by use of fertiliser efficiency (depends on type of manure: slurry/deep litter/solid manure etc.). Emissions are calculated based on the modelled input of fertiliser (N-balance).	Use of fertiliser is modelled as the actual mix of mineral fertilisers and manure. Emissions are calculated based on the modelled input of fertiliser and manure (N-balance). Emissions relating to manure are the ones after storage.
Removed straw for energy	Included transport of straw and combustion in biomass CHP. Generated energy substitutes marginal heat and electricity (see **section 4.4** and **4.5**).	Revenue (economic) allocation between crops and straw.
Agriculture: dairy cow system		
Manure	Emissions associated with the handling and field application of manure are included. The fertiliser effect of the applied manure is modelled as substituted mineral fertiliser and associated emissions related to field application. The substitution rate is based on the fertiliser efficiency of manure (depends on type of manure: slurry/deep litter/solid manure etc.).	Emissions after storage are cut-off – this is included as part of the plant cultivation. Allocation to milk and meat is 100% (given by IDF 2010, see below), hence 0% is allocated to the fertiliser value of manure.
Raw milk/meat	Surplus calves and culled cows sent to slaughter are modelled as substituted beef production. The substituted beef is modelled as Brazilian beef production (since this is identified as the marginal on the world market for beef).	Allocation between milk and beef based on allocation model in IDF (2010): biophysical allocation.
Food and feed industry		
By-products: The following by-products are used as feed: rapeseed, sunflower and palm kernel meals, molasses, DDGS, whey, brewer's grains, malt sprouts, bran.	By-products are constrained by the demand for the associated joint reference products. Therefore, the use of by-products as feed is modelled with the marginal supply of feed energy (barley) and feed protein (soybean meal) on the world market. Amount of energy and protein based on feed composition data.	The use of by-products as feed is modelled by revenue (economic) allocation between by-products and reference products.
Reference products: palm and rapeseed oil, soybean meal, sugar, milk, cheese.	The demand for reference products determine the production volume of the supplying industries. Therefore, the use of these products is modelled by including all upstream flows and by substitution for their by-products.	The use of reference products is modelled by revenue (economic) allocation between by-products and reference products.
Energy		
Electricity	Marginal electricity mix. This is estimated based on future predictions (2010-2020) of the expansion of national electricity supply. See **section 4.4**.	Average use electricity mix. This based on national use mixes in 2010. See **section 4.4**.
District heating	Marginal district heating supply. This has been identified as biomass CHP. Electricity by-product is modelled using substitution (See **section 4.5**).	The use of district heating is insignificant in the product system relating to Arla Foods' product portfolio. Therefore, the same modelling of heat as used in consequential model is used here. By-products of heat are present at several places in the product system. Since this is modelled using revue allocation, there is no need for district heating data.

Waste treatment and recycling		
Supply of waste	When waste is sent to incineration, all emissions from the waste incineration are included, and energy by-products are modelled using substitution. Similar, when waste is sent to recycling all emissions related to the recycling process are included, and the recovered materials (by-products) are modelled using substitution.	Same as consequential modelling.
Use of waste: use of recycled materials.	Recycled materials are constrained by the amount of waste sent to recycling. Therefore, the use of recycled materials is modelled as virgin materials.	Same as consequential modelling.

3.2 Indirect land use changes (iLUC)

According to IPCC (2013), 8% of global GHG emissions (GWP100) are caused by CO_2 emissions from land use changes. It has been chosen to use a model for iLUC proposed by Schmidt et al. (2015). This model has been used for a large number of LCA studies and carbon footprints, for example the carbon footprint of Denmark's production and consumption, published by the Danish Energy Agency (Schmidt and Muñoz 2014). The model has been and is currently being developed through an initiative lead by 2.-0 LCA consultants: The 2.-0 iLUC club (http://lca-net.com/clubs/iluc/). The initiative is supported by more than 20 partners including large multinational companies, national research centres, NGOs and universities. The partners are located in 11 different countries in Europe, Asia, North America and Australia.

The iLUC model has several key characteristics that make it superior to many of the other models:

- It is applicable to all crops (also forest, range, build etc.) in all regions in the world.
- It overcomes the allocation/amortisation of transformation impacts.
- It is based on modelling assumptions that follow cause-effect relationships and standard modelling consistent with any other LCA-processes.

According to (Schmidt et al. 2015), the cause of land transformation can be explained by changes in the demand for land. One of the challenges when modelling land use changes is to ascribe the observed land use changes to its drivers – namely changes in demand for land. The mechanisms are illustrated in **Figure 3.3**. The figure uses the example of changing the demand for land for rapeseed in Denmark by 1 ha*year. It appears from the figure that the land use effects can be divided into direct and indirect land use changes. This is further explained in the following.

Direct land use change (dLUC): The direct land use change includes the effect from changing from a reference situation to rapeseed. The reference situation is the current marginal use of arable land, i.e. crop cultivation. Most often, the direct land use changes are small, so that the carbon stock and biodiversity hosted on the land are the same for the specific use and for the reference. This means that as long as arable land is used for purposes that have a similar carbon stock and biodiversity, the direct land use impacts are zero. However, there are cases where direct land use changes are not zero. This is when the specific land use hosts different carbon and/or biodiversity than the reference. These effects can be negative (good) when the specific land use hosts more carbon and biodiversity than the reference (which could be the case for extensive grassland or organic farming), and they can be positive (bad) when the specific land use hosts less carbon and biodiversity than the reference (e.g. sealed land: land for roads and buildings).

Indirect land use change (iLUC): It appears from **Figure 3.3** that the indirect consequence of the direct land use change is the occupation of some production capacity that needs to be compensated somewhere else. When occupying 1 ha*year in a specific country/region, this needs to be adjusted for its productivity, in order to be comparable with a global average ha*year. Schmidt et al. (2015), propose to measure this using potential net primary production (NPP_0). Hence, the adjustment factor is calculated as the actual NPP_0 divided by the global average NPP_0 for arable land. When this adjustment is done the unit is changed from ha*year to ha*year-equivalents, where 1 ha*year-equivalent refer to land with global potential average productivity. According to **Figure 3.3**, the compensation of production capacity for displaced crops partly takes place as land transformation and partly as intensification. Observing time series of global agricultural statistics (FAOSTAT 2015), it can be found that out of the overall change in the output of crop cultivation from 2000 to 2010 (dry matter mass basis), 63% comes from increases in yields (intensification), and 37% comes from expansion of the cultivated area (transformation). So when an occupation of 1 ha*year-equivalent needs to be compensated, this is modelled as 0.63 ha*year-equivalent from intensification and 0.37 ha*year-equivalent from transformation.

Different markets for land: Schmidt et al. (2015) operate with different markets for land: 1) Arable land, 2) Intensive forest land, 3) Extensive forest land, and 4) Grassland. The markets for land delimit land types with different potential uses, and the potential uses represent the reference for each land type. E.g. grassland in the dry Brazilian Cerrado, which is to a large extent used for cattle grazing, cannot be used for forestry or arable cropping because it is too dry for these purposes. Therefore, a change in the use of these grasslands will not have any indirect effects on the markets for forest land or arable land. Similarly, forest land in Northern Sweden is not fit for arable cropping because the land is too rocky and hilly for that purpose. Therefore, the use of this land will only affect the market for forest land. Sometimes land is used for less productive purposes (economically) than the land's potential use, e.g. when arable land in Denmark is used for animal grazing. In this case, the indirect effects will still affect the market for arable land.

The further details of the applied iLUC model are available in Schmidt et al. (2015) and Schmidt and Muñoz (2014).

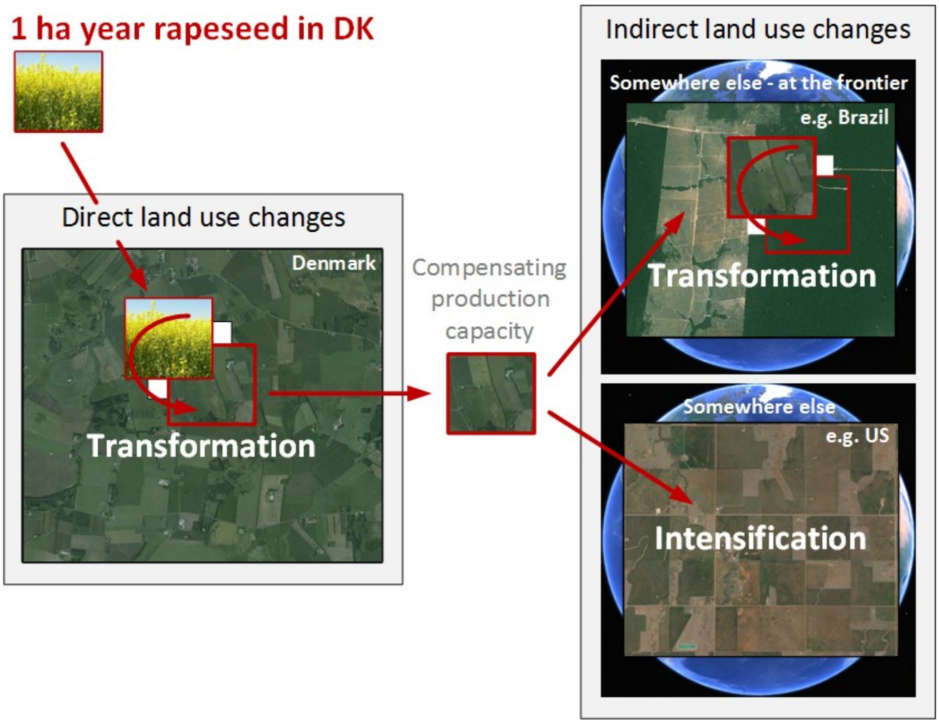


FIGURE 3.3, ILLUSTRATION OF THE EFFECTS OF CHANGING THE DEMAND FOR LAND IN DENMARK WITH ONE HECTARE*YEAR: DIRECT AND INDIRECT LAND USE CHANGES.

3.3 Life cycle impact assessment (LCIA): Mid-point evaluation

To obtain a comprehensive understanding of the full environmental impact of Arla Foods, the following environmental impact categories are included:

- Global warming
- Eutrophication
- Acidification
- Respiratory effects
- Resource use (energy, water and minerals)
- Nature occupation (biodiversity)
- Photochemical ozone formation
- Human toxicity (carcinogenic and non-carcinogenic)
- Ecotoxicity (aquatic and terrestrial)

Ozone depletion has been excluded. This is due to lack of data on emissions of ozone depleting substances mainly from cooling in dairy production sites and in retail. The monetarised impact of ozone depletion is estimated as being insignificant – mainly because ozone-depleting substances are being significantly reduced/phased out because of the Montreal Protocol, which came into force in 1989.

For global warming, biogenic CO_2 uptake and emissions have been eliminated, except for land use change emissions where emissions of biogenic CO_2 contributes. According to Schmidt et al. (2015), net land use emissions are zero – only the timing of emissions is affected. The effect of timing of CO_2 emissions is modelled consistent with the GWP100 method (IPCC 2013). For further details, see Schmidt et al. (2015).

The impacts are evaluated using the Stepwise method v1.5 (Weidema et al. 2007). Further, this version is updated making the modelling of nature occupation (biodiversity) consistent with a general way to model indirect land use changes. This is described in **section 3.4**. All above-mentioned impacts are monetarised in the end-point evaluation (see **sections 3.5** and **3.6**)

In addition to the above-mentioned impact categories, some additional indicators are also included. The reason why these are included is that they correspond to some of Arla Foods' environmental goals. These additional indicators are overlapping with the impacts above; therefore, they are not included in the monetarisation. The impacts are:

- Water use (quantity as blue water footprint)
- Land occupation

3.4 Updates of the Stepwise method

3.4.1 Global warming potential aligned with IPCC (2013)

More than 99.9% of the contribution to global warming in the current study is caused by carbon dioxide (CO_2), methane (CH_4) and nitrous oxides (N_2O). With the newest assessment report from IPCC (IPCC 2013), the characterisation factors (GWP100) for methane and nitrous oxides have been updated from 25 to 28 kg CO_2-eq/kg and 296 to 265 kg CO2-eq/kg respectively. The characterisation factors for these two emissions have been updated accordingly in the Stepwise method.

3.4.2 Nature conservation

In the current Stepwise method (version 1.5) (Weidema 2009; Weidema et al. 2007), biodiversity is modelled using an average approach for including biodiversity effects from indirect land use changes. The modelling in current version of Stepwise implies that:

1) the effects on biodiversity are overestimated because the "iLUC modelling" in Stepwise does not consider intensification, i.e. all changes in demand for land affects denaturalisation (deforestation), and that
2) the full cause effect pathway from land occupation to nature occupation (biodiversity) is inherently carried out in Stepwise (in the life cycle impact assessment phase, LCIA), while other effects from indirect land use changes (e.g. GHG emissions) need to be modelled in the life cycle inventory phase (LCI). This is inconsistent.

The nature occupation impact method in Stepwise v1.5, has therefore been revised. The revision makes the biodiversity LCIA compliant with a more general modelling of indirect land use changes as described in **section 3.2** and Schmidt et al. (2015). The revision involves splitting up the aggregated nature impact in Stepwise into direct and indirect impacts. The revision is described in the following.

Relationship between land occupation and BAHY: In the current version of Stepwise, occupation of 1 ha*year arable land has an impact of 0.88 BAHY. According to Weidema et al. (2008, p 157), this is calculated as the annual global deforestation divided by the current global use of arable land (this gives a figure on average deforestation per unit of land occupation), multiplied by 500 (this is the relaxation time for biodiversity), and multiplied by 0.2 (this is a severity factor talking into account that there is some biodiversity during the 500 years). However, this approach to establishing a link between land occupation and BAHY is not compatible with more recent findings on pathway modelling from land occupation to land transformation; According to Schmidt et al. (2015), a change in demand for 1 ha*year land has the effect that denaturalisation of one hectare is moved one year closer. According to Weidema et al. (2008, p 157), arable land hosts only 20% of the species compared to the number in nature at full relaxation. Therefore, one ha*year arable land corresponds to 0.8 BAHY. Furthermore, the monetarisation in the current version of Stepwise refers to EUR/agricultural land (agricultural land equivalents is used as midpoint indicator) while the updated version uses BAHY as mid-point – therefore the updated monetarisation must refer to EUR/BAHY. This update is made by dividing the current monetarisation factor by 0.88.

Direct land use change: As described in **section 3.2**, direct land use effects are normally of often of minor importance, and as long as arable land is used for purposes that have similar direct impact on nature occupation (biodiversity) as average arable cropping, no direct land use impacts need to be added/subtracted. However, in cases where a specific land use is associated with a different direct impact than average arable cropping, this effect is included as direct effects. E.g. when arable land is used for non-fertilised grassland (which supports higher biodiversity than arable cropping), the direct biodiversity impact will be the impact of grassland minus the impact of average arable land (see negative direct impacts in **Table 3.3**).

Indirect land use change: As described in **section 3.2**, indirect land use changes include transformation and intensification. Intensification has no effects on nature occupation. The effects from intensification are included via other impact pathways, e.g. biodiversity effects from terrestrial eutrophication from losses of nutrients due to increased fertiliser application. In the following, land transformation via indirect land use changes is referred to as accelerated denaturalisation. This term is used because the effect on denaturalisation, such as deforestation from a specific land occupation (1 ha*year-equivalent), is only temporary, moving the denaturalisation of one ha*year-equivalent one year closer, see Schmidt et al. (2015), hence the term accelerated. The accelerated denaturation related to occupation of arable land includes transformation from secondary forest to cropland (Schmidt et al. 2015). The effect in units of biodiversity midpoint indicator (BAHY) is calculated as the difference in biodiversity-value of secondary forests and cropland. This is then multiplied by the duration, which is one year, and the area. It should be noted that since some of the indirect land use changes involve compensation of land for displaced crops via intensification, occupation of 1 ha*year-equivalent induce less than 1 ha*year-equivalent accelerated denaturalisation.

The updated characterisation factors for nature occupation (indirect and direct impacts per unit of land use) are listed in **Table 3.3**. In **Table 3.3**, it can be seen that the direct impact plus the indirect impact is equal to 1 when occupying sealed land (and assuming that no intensification dampens the indirect effect).

In **Appendix 2: Numerical example of land use changes**, an example of the calculation of the biodiversity global warming impact of 1 ha*year unfertilised grassland in Denmark is presented.

TABLE 3.3: CHARACTERISATION FACTORS FOR 1 HA*YEAR LAND OCCUPATION AND 1 HA*YEAR INDIRECT DENATURALISATION IMPACT. THE CHARACTERISATION FACTORS ARE ALL BASED ON STEPWISE (WEIDEMA ET AL. 2007), THE DIFFERENCE IS THAT THEY ARE DIVIDED INTO DIRECT AND INDIRECT HERE, MAKING IT COMPATIBLE WITH THE MORE GENERAL MODELLING OF INDIRECT LAND USE CHANGES IN SCHMIDT ET AL. (2015). THE VALUES HAVE BEEN ADOPTED FROM ECOINDICATOR99 (GOEDKOOP AND SPRIENSMA 2001) BY MAINTAINING THE ORIGINAL PROPORTION BETWEEN DIRECT IMPACT INDICATOR VALUES, RELATIVE TO THE VALUES FOR INTENSIVE AGRICULTURAL AND URBAN USE OF ARABLE LAND.

Land markets and uses	Direct marginal impact relative to marginal land use BAHY	Indirect denaturalisation impact BAHY
Arable land		
Intensive agricultural and urban use of arable land		
Occupation, accelerated denaturalisation, secondary forest to arable*	n.a.	0.8
Occupation, arable	0	n.a.
Occupation, pasture and meadow, intensive		
Occupation, urban, continuously built		
Occupation, sealed, on arable land*	0.2	
Less intensive uses of arable land		
Occupation, arable, organic	-0.04	n.a.
Occupation, forest, on arable land*	-0.7	
Occupation, industrial area, built up	-0.22	
Occupation, pasture and meadow, extensive	-0.09	
Occupation, traffic area	-0.22	
Intensive forest land		
Occupation, accelerated denaturalisation, secondary forest to intensive forest*	n.a.	0.1
Occupation, accelerated denaturalisation, primary forest to intensive forest*		0.1
Occupation, forest	0	n.a.
Occupation, sealed, on intensive forest land*	0.9	
Extensive forest land		
Occupation, accelerated denaturalisation, secondary forest to extensive forest	n.a.	0.1
Occupation, accelerated denaturalisation, primary forest to extensive forest		0.1
Occupation, forest, extensive	0	n.a.
Occupation, sealed, on extensive forest land*	0.9	
Grassland		
Occupation, accelerated denaturalisation, grassland to pasture	n.a.	0.3
Occupation, grassland	0	n.a.
Occupation, sealed, on grassland*	0.7	

3.5 Life cycle impact assessment (LCIA): End-point evaluation / monetarisation

The Stepwise Valuation method is documented in Weidema (2009). Stepwise provides impact pathways for the following three safeguard subjects: Human wellbeing, Ecosystems, Resource productivity (Weidema 2009; Weidema et al. 2007).

The first step of the calculation of monetarised impacts in the stepwise method is to relate each of the mid-point characterised results in life cycle impact assessment (LCIA) to the three safeguard subjects mentioned above. Ideally, an endpoint impact assessment method should reflect the absolute prevalence, duration and severity of the impact described by each impact category. The damage categories are defined so that they can be measured in terms of Quality Adjusted Life Years (QALYs) for impacts on human well-being, Biodiversity Adjusted Hectare Years (BAHYs) for impacts on ecosystems, and monetary units for impacts on resource productivity. This preparation of mid-point characterisation model for monetarisation is documented in Weidema et al. (2007). QALYs are identical to the concept of disability-adjusted life years, DALY (just with opposite sign).

All individuals are given equal weight irrespectively of socio-economic status (Weidema 2009). The BAHY concept is similar to the potential disappeared fraction of species (PDF), i.e. the impact is expressed in terms of the fraction of species that are affected per unit of area and time. Resource productivity is expressed as the additional cost for future extraction as a result of current dissipation.

The second step of the calculation of monetarised impacts in the stepwise method is to estimate the value of one QALY as the potential average annual income per capita. This is based on the budget constraint approach (Weidema 2009). Since a QALY by definition is a life-year lived at full well-being, the budget constraint can be determined as the potential annual economic production per capita at full well-being. An average annual income is the maximum an average person can pay for an additional life year at full wellbeing. The monetary value of a QALY is determined as 74,000 EUR with an uncertainty estimate of 62,000 to 84,000 EUR.

The third step is to determine the relative value of ecosystems (measured in BAHY) compared to human wellbeing (QALY). 1 BAHY refers to 1 ha*year with a land use type that does not allow any species to grow, e.g. sealed land. Weidema (2009) explores different options for arriving at this value and finally settles for a proxy value corresponding to valuing the current global ecosystem impacts at 2% of the value of a QALY, i.e. 2% of the potential income, noting that the current environmental protection expenditures in developed countries are at 1–2% of GDP. Using a normalisation value for the current global ecosystem impacts of 50% of the terrestrial area ($13 \cdot 10^9$ ha), corresponding to 1.05 ha*years per person, this gives a value of 1400 EUR/BAHY (74,000 EUR * 2% / 1.05 BAHY) with an uncertainty estimate of 350 to 3500 EUR. Weidema (2009) notes that the proxy value is close to the value of 1500 EUR/BAHY derived from the only available choice modelling study that had explored this issue.

Since the impact of resource extraction is already measured in monetary value, there is no need for further valuating this. The monetarised impacts per unit of mid-point impact in the Stepwise method are summarised in **Table 3.4.**

The most prominent advantages of the Stepwise method are that:

- The valuation of all impacts is based on the same basic approach, which makes the method very consistent and reduces the uncertainties compared to other valuation methods.
- It is based on mid-point impacts to which thousands of emissions are related via dose-response models in existing life cycle impact assessment methods, which makes it very complete in terms of included pollutants.

It should be noted that the Stepwise method currently does not include discounting.

TABLE 3.4: SUMMARY OF DAMAGE ENDPOINT FACTORS FOR THE STEPWISE METHOD. THE UPDATES IN SECTION 3.4 ARE INCLUDED (WEIDEMA 2009; WEIDEMA ET AL. 2007). EUR REFERS TO EUR2003. THE FINAL RESULTS ARE SHOWN IN EUR2014. BASED ON EUROSTAT (2015A), A CONVERSION RATE AT 1.38 EUR2014/EUR2003 CAN BE CALCULATED.

Impact category	Units of characterised values at midpoint	Impacts on ecosystems		Impacts on human well-being		Impacts on resource productivity	All impacts aggregated
		BAHY/ characterised unit at midpoint	EUR/ characterised unit at midpoint	QALY/ characterised unit at midpoint	EUR/ characterised unit at midpoint	EUR/ characterised unit at midpoint	EUR/ characterised unit at midpoint
Acidification	m² year UES	5.5E-06	7.7E-03				7.7E-03
Ecotoxicity, aquatic	kg-eq. TEG water	5.0E-09	7.1E-06				7.1E-06
Ecotoxicity, terrestrial	kg-eq. TEG soil	7.9E-07	1.1E-03				1.1E-03
Eutrophication, aquatic	kg NO_3-eq.	7.2E-05	1.0E-01				1.0E-01
Eutrophication, terrestrial	m² UES	8.9E-06	1.3E-02				1.3E-02
Global warming	kg CO_2-eq.	5.8E-05	8.2E-02	2.1E-08	1.6E-03	-3.7E-04	8.3E-02
Human toxicity	kg C_2H_3Cl-eq.			2.8E-06	2.1E-01	6.4E-02	2.7E-01
Injuries, road/work	fatal injuries -eq.			4.3E+01	3.2E+06	9.9E+05	4.2E+06
Ionizing radiation	Bq C-14-eq.			2.1E-10	1.6E-05	4.8E-06	2.0E-05
Mineral extraction	MJ extra					4.0E-03	4.0E-03
Nature occupation	BAHY	8E-05	1.4E-01				1.4E-01
Ozone layer depletion	kg CFC-11-eq.			1.1E-03	7.8E+01	2.4E+01	1.0E+02
Ph. chem. ozone – veg.	m²*ppm*h	6.6E-08	9.3E-05				
Respiratory inorganics	kgPM2.5-eq.			7.0E-04	5.2E+01	1.6E+01	6.8E+01
Respiratory organics	Pers*ppm*h			2.6E-06	2.0E-01	6.1E-02	2.6E-01

Performing an additional assessment of distributional issues would allow accounting for the environmental injustice hypothesis. This hypothesis states that low-income groups are exposed to higher environmental risks than high-income groups. However, this issue is currently not included in any of the immediately available methods for valuation.

3.6 Life cycle impact assessment (LCIA): Alternative monetarisation methods

As alternatives to the valuation in Stepwise, the valuations proposed by the Danish Energy Agency and Environmental Protection Agency (Energistyrelsen 2014b; Andersen and Brandt 2014) as well as of Trucost in Høst-Madsen et al. (2014) are used for sensitivity analysis. The valuations of Stepwise and the two alternative methods are shown in **Table 3.5**.

The Stepwise method includes many more emissions than the other two sets of methods. For the comparison in **Table 3.5**, only those emissions included in the other sets are included.

In the Danish method, the values for CO_2-equivalents are based on the quota-price, which is not a damage cost but rather a direct pecuniary expenditure, and which implies the assumption that the quotas have a global effect, i.e. that the quota-emissions are not exported to other non-quota countries and that the additional CO_2-equivalents therefore does not have any uncompensated environmental effect. This is in stark contrast to the assumption in Stepwise and Trucost, where the quotas are not expected to have any effect on the global emission levels and where the full damage is therefore included as an externality and monetarised.

For the other emissions, all three methods are using the impact pathway method, which means that the fate, exposure and effect is first modelled in physical terms, and the resulting effect measure is then monetarised with a willingness-to-pay value (e.g. for impacts on humans, a value for a healthy life-year), possibly temporally discounted. Differences between the methods can therefore arise from differences in physical modelling, differences in the willingness-to-pay measure, and differences in discounting.

For the Danish guidelines, several different values for several different exposure scenarios are given. In **Table 3.5**, these are represented as low/average/high valuation. Low typically represents larger combustion plants in the energy sector while high typically represents emissions from road traffic. The Danish guidelines also differentiate between urban and rural for some emissions (mainly traffic). This is not shown here – only the ranges are shown.

TABLE 3.5: COMPARISON OF MONETARISATION OF EMISSIONS IN THREE DIFFERENT SETS OF METHODS. ALL EMISSION FACTORS AVAILABLE IN THE DANISH GUIDELINES AND TRUCOST ARE SHOWN, WHILE ONLY A SMALL FRACTION OF THE EMISSION FACTORS IN STEPWISE ARE SHOWN.STEPWISE AND TRUCOST REPORT THE MONETARISATION IN EUR, WHILE THE DANISH GUIDELINES ARE IN DKK. THE LATTER (DKK2013) HAS BEEN CONVETED TO EUR2013 BY USING 1 EUR2013 = 7.4579 DKK2013 (EUROSTAT 2015C).

Emissions	Stepwise (EUR2003/kg) (section 3.5)	Danish Guidelines (EUR2013/kg) Danish EPA: (Andersen and Brandt 2014) Danish Energy Agency (2014)			Trucost (EUR2011/kg) (Høst-Madsen, Damgaaard, Szeler, et al. 2014)	
		Low	Average	High	Global	Denmark
Ammonia (NH_3)	10.2	20.9	20.9	20.9	0.632	0.400
Carbon dioxide (CO_2-eq)	0.0830	0.00737	0.00737	0.00737	0.0860	0.0860
Carbon monoxide (CO)	0.317	0	0	0.0013		
Lead	145	14.0 [a]	95 [a]	424[a]		
Nitrogen oxides (NO_x)	9.69	5.23	15.4	15.4	1.30	0.577
NMVOC	0.246				0.875	0.374
Particulates < 2.5um ($PM_{2.5}$)	67.6	18.9	27.4	44.2		
Particulates < 10um (PM_{10})	36.2				12.5	7.75
Sulphur dioxide (SO_2)	5.42	12.3	35.4	55.6	0.972	1.53

[a] Calculated proportionally to the rural, average and urban population densities (20, 135 and 600, respectively)

The physical modelling in Stepwise includes impacts on natural ecosystems and on crops, while – for the emissions in **Table 3.5** – the other method sets only include impacts on humans. When comparing the method results at the level of the physical modelling, i.e. when back-calculating the results using the same willingness-to-pay value and the same discounting, the physical modelling results in Trucost appear to be generally lower than those of Stepwise, which again are lower than those of the average results with the Danish method. The physical modelling in the Danish method is more recent than that in the other two methods, and can therefore be based on more recent knowledge and more accurate modelling. Exceptions occur for NMVOC, where the Danish method only includes the indirect effect via ozone, which is negligible without a simultaneous reduction in NO_x, and for CO where the Danish method does not calculate the exposure directly but only as a factor of the NMVOC emission.

The values for a human life-year applied by the three methods are different, with Trucost having a value corresponding to 14,200 EUR_{2013}/life-year, more than 5 times lower than that of the Danish method (78,000 EUR_{2013}/life-year), and Stepwise having a value of 121,000 EUR_{2013}/life-year, which includes an additional separate impact on productivity.

The discounting in the three methods are also different, with no discounting in Stepwise, a stepwise decreasing discounting in the Danish method (4% for the first 35 years, then 3% until year 70 and then a constant 2.5% after 70 years) and an apparently fixed discounting in Trucost (only mentioned for global warming with a time-invariant 1.4%). To assess the importance of these differences for the results it would be necessary to have access to the temporally differentiated results of the physical modelling, but these are not published, neither for the Trucost nor for the

Danish method. We can however estimate the effect of the discounting in the Danish method to approximately a halving of the undiscounted values.

4. Life cycle inventory: Background system

4.1 Input-output database: FORWAST

The input-output database used is the FORWAST database. The first version of the database was created as part of the EU FP6 project FORWAST, finalised in 2010 (http://forwast.brgm.fr/). As part of the project, environmentally extended IO-models were developed for all EU27 countries. This was aggregated to a EU27 IO-model. As part of the project, there was special focus on Denmark; therefore, the Danish IO-model was trade-linked with the EU27 model. Hence, the GHG emissions embodied in imports to Denmark were modelled as if they were produced in EU27.

The FORWAST database is available as a standard database in the LCA software SimaPro. Its methodology is described in Schmidt et al. (2010). A detailed description of all data for Denmark can be found in Hafner et al. (2010, chapter 4). Documentation of data for all other EU27 countries can be found in Hafner et al. (2010) and Rejman-Burzyńska et al. (2010). The elaborated core data sets used for the creation of the model are available as country-specific Excel files in: http://forwast.brgm.fr/results_deliver.asp (deliverables 3.2 and 4.2). It should be noted that the original model referred to above has been further refined. This has been done as part of three separate studies:

Hermansen et al. (2010):

- Danish agriculture and food industry has been further detailed.
- More emissions have been added: nitrate, phosphate.

Kjær et al. (2011):

- More emissions have been added: particles.
- Imports to Denmark is divided into imports from EU27 and from rest of the world (RoW).

Schmidt and Muñoz (2014):

- Land occupation has been added as a resource input in the database.
- A model for indirect land use changes has been embedded in the model. The iLUC model is described in **section 3.4** and **4.9**.

It should be noted that the FORWAST database has been used to calculate the carbon footprint of Danish production and consumption published by the Danish Energy Agency in 2014 (Schmidt and Muñoz 2014).

The FORWAST input-output database does not only account for monetary transactions in the economy, but also, as a mirror of the monetary economy, physical tables in mass units were created. This also included the establishment of mass balances for each industry in each country, which enabled for calculating the waste flows. Waste flows can principally be calculated as inputs to economy (resources) minus outputs (emissions). This calculation was further detailed by tracking the fate of each input of each product to each industry. The creation of physical tables, created a number of new features for the use and quality for IO-modelling:

- **Consistency checks:** When having IO-models in monetary units only, there is no check of how well the modelled inputs and outputs of products of each industry reflect the real world. E.g. when just using the pure monetary tables, it was discovered that many feedstock/raw materials in manufacturing industries were missing. Further, the introduction of physical data also allowed for differentiation of prices over industries and to match with other detailed data on e.g. energy use and raw material input per unit of output for the different industries.
- **National waste accounts:** can be calculated
- **National mass flow accounts:** can be calculated

4.2 Materials

In this section, the inventory data for materials used at Arla Foods are described.

4.2.1 Raw milk

Life cycle inventory data on the use of raw milk are obtained from Cenian et al. (2015). The inventories are modelled using the methods as described in Schmidt and Dalgaard (2012a). The inventories in Cenian et al. (2015) include the following national average data on raw milk at farm gate:

- Denmark 2012
- Germany 2012
- Sweden 2012
- United Kingdom 2012

In cases where data for raw milk in other countries are needed, an unweighted average of the four data sets above are used. This is mainly used for raw milk in the Netherlands, Finland and United States. Smaller amounts of milk from Canada and Mexico are also modelled using these data.

The LCI data above are available in both a consequential and an attributional version.

It should be noted that Cenian et al. (2015) mainly focuses on GHG emissions, while the scope of the current project is wider. Therefore, the datasets in Cenian et al. (2015) are supplemented with more complete background data. This includes:

- All building blocks in Cenian et al. (2015), i.e. the background databases, are linked to ecoinvent v3.1 (ecoinvent 2014) + service add-on based on the FORWAST database (see **section 4.1** and **4.3**).
- When linking to the ecoinvent database, instead of using the pre-calculated GHG emissions from fertiliser in Cenian et al. (2015), it is no longer taken into account that ecoinvent overestimates nitrous oxide emissions from nitric acid (which issued for ammonium based N-fertilisers). Therefore, the nitric acid datasets[2] from ecoinvent are modified to represent current emissions levels of nitrous oxide. The specific reduction is described in Cenian et al. (2015, p 15).
- Pesticide data have been added to all crop LCIs in the model in Cenian et al. (2015). This includes both LCI data for the manufacturing and transport of pesticides and the emissions to soil in the field. The applied data are obtained from ecoinvent 3.1 (ecoinvent 2014). It should be noted that the crop LCIs from ecoinvent 3.1 do not match with the locations for crops in the milk. Therefore, representative locations have been assumed, e.g. the same amount and types of pesticides have been applied to the same crops in Denmark, Germany, Sweden and United Kingdom.
- Water and irrigation data have been added to all crop LCIs in the model in Cenian et al. (2015). Data on water consumption are obtained from Mekonnen and Hoekstra (2010), and the applied irrigation LCIs are from ecoinvent 3.1 (ecoinvent 2014). Data on the water consumed by the cattle and in the milking parlour are country specific and based on data from the CREEA project (creea.eu).

4.2.2 Butter

Arla Foods uses some minor amounts of butter supplied by other dairies (6,300 tonne in 2014). The LCI data are based on the following aggregated dataset '_20 Dairy products, DK' from the FORWAST database (see **section 4.1**). The consequential and attributional versions are made applying the following modifications to this dataset:

- **Consequential:** Butter is considered as a joint by-product of milk and cheese production; hence, a change in demand for butter will affect neither the use of raw milk nor the output of milk-based dairy products. Instead, a change in demand for butter will be met by an additional input of vegetable oil to the dairy industry. Therefore, when modelling butter, the inputs of raw milk to the FORWAST dataset are deleted and then replaced by an input of vegetable oil. The marginal source of vegetable oil is palm oil (Schmidt 2015). The LCI data for palm oil are described in the section below. The dataset from FORWAST has a reference flow in dry matter mass unit. Butter has a dry mater content at 84% (Wholefoodcatalog 2015a).
- **Attributional:** The original input of raw milk in the FORWAST dataset is replaced with the data on raw milk described in the previous section (Dalgaard et al. 2015a). Dry matter contents at 84% for butter and 12% for raw milk are used (Wholefoodcatalog 2015a).

4.2.3 Cheese

Arla Foods uses some minor amounts of cheese supplied by other dairies (7,900 tonne in 2014). The LCI data are based on the following aggregated dataset '_20 Dairy products, DK' from the FORWAST database (see **section 4.1**). According to Nielsen et al. (2005), the use of raw milk per kg cheese is 10 kg. The original input of raw milk in the dataset is replaced with the LCI data

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[2] Nitric acid datasets in ecoinvent v3.1:
- 'Nitric acid, without water, in 50% solution state {RER}| nitric acid production, product in 50% solution state'
- 'Nitric acid, without water, in 50% solution state {ROW}| nitric acid production, product in 50% solution state'

described in the section above (Dalgaard et al. 2015a). The used aggregated FORWAST dataset has a reference flow in units of kg dry matter weight. Dry matter contents of cheese is 60% (Wholefoodcatalog 2015a). Cheese production is associated with a by-product of 0.17 kg butter/kg cheese (Lambert 1988) and whey for feed or other. 1 kg dm whey contains 8.76 MJ net energy and 0.13 kg crude protein (Møller et al. 2005). The dry matter contents of raw milk, cheese and butter are from '**Appendix 1: Fuel and** dairy product properties'. Based on the product flow and dm%, a mass balance is established, see **Figure 4.1**.

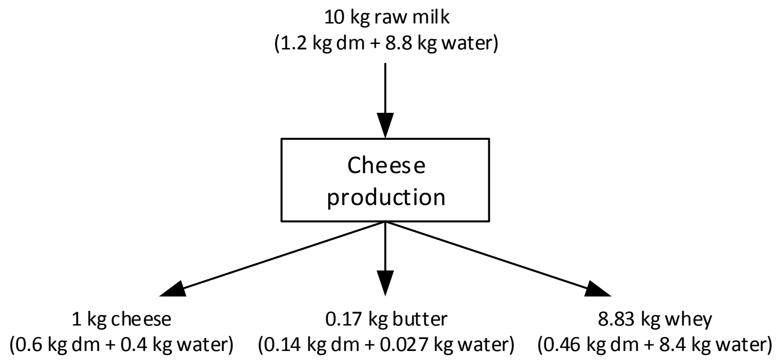

FIGURE 4.1: MASS BALANCE OF CHEESE PRODUCTION.

The consequential and attributional versions are made applying the following modifications to this dataset:

- **Consequential:** The by-products of butter, feed energy and protein are modelled using substitution. Butter is modelled using the LCI data described in the section above. The LCI data for generic feed are obtain from (Dalgaard et al. 2015a).
- **Attributional:** The by-products of butter and whey for feed are eliminated from the system by allocation. An allocation factor based on milk solids (represented by dry matter content) is used. The allocation factor is calculated as 50% based on **Figure 4.1**.

4.2.4 Powder

Arla Foods used 18,000 tonne of powders purchased from other dairies in 2014. In the modelling, at is assumed that the powder can be represented by milk powder. The LCI of milk powder is obtained from Dalgaard and Schmidt (2014).

4.2.5 Whey

Arla Foods uses large amounts of whey. In 2014, the use of whey provided from external dairies was 2,420,000 tonne. It should be noted that this is in units of thin whey with 5.2% dm (this is assumed based on the flows in **Figure 4.1**). The consequential and attributional versions of whey are modelled as follows:

- **Consequential:** Since whey is a constrained by-product from cheese production, the use of whey will affect the marginal use of whey, which can be identified as animal feed. The feed energy and feed protein content in dry matter whey is obtained from Møller et al. (2005) and LCI data for generic feed energy and feed protein are obtain from Cenian et al. (2015).
- **Attributional:** Whey is a by-product of cheese production. Therefore, whey can be modelled using the same dataset as for cheese, but just with another allocation factor, but same approach as for cheese. The allocation factor can be calculated as 38%. This is based on a dry matter mass balance of cheese making (**Figure 4.1**).

4.2.6 Vegetable oils

This is modelled as 64% refined rapeseed oil and 36% refined palm oil. This is based on data provided by Arla Foods. It should be noted that the data specify 19% other vegetable oils (this mainly refers to blends where the specific composition is not known). The data sets for rapeseed and palm oil are described in Dalgaard and Schmidt (2012), and these data have been updated according to Schmidt (2015). These LCI data are available in both a consequential and an attributional version.

4.2.7 Salt

Data set from ecoinvent: 'Sodium chloride, powder {GLO}| market for' (ecoinvent 2014) plus services add-on (see **section 4.3**).

4.2.8 Fruits-jam

Data set from FORWAST: 'EU27 _21 Fruits and vegetables, processed' (see **section 4.1**). Average dry matter at 30% has been assumed. Except from the electricity mix and inclusion of iLUC, there is no difference for the consequential and attributional version of the used LCI data.

4.2.9 Orange and apple juice

Rynkeby, a daughter company of Arla Foods that produces juices, uses raw juice as their raw material. More than 80% of this is from oranges (54%) and apples (27%). Therefore, all input of raw juice to Rynkeby has been modelled using 67% oranges and 33% apples as representative.

In terms of mass, Rynkeby's products only account for 1.5% of all Arla's products. Therefore, the raw juice from oranges, apples and other fruits/vegetable inputs to Rynkeby are not modelled in detail. All fruit/vegetable cultivation is modelled using the product category 'Crops n.e.c.' from EU27 in the FORWAST database. The data in the FORWAST database are per kg dry matter. The dm% for oranges and apples are 13% (Hinton 2007) and 15% (Wholefoodcatalog 2015a) respectively.

The inputs and outputs of the raw juice production activity are modelled using the following activity in the FORWAST database: 'Fruits and vegetables, processed' from EU27. In order to better represent juice production, the inputs of raw materials (oranges and apples) and energy use (related to drying) as well as outputs of by-product: citrus peels and apple pomace for animal feed have been modified. This is shown in **Table 4.3**.

77% of the raw juice (ww basis) used by Rynkeby is concentrates. The strength of orange juice concentration is 6, i.e. 1 litre raw orange juice is concentrated to 1/6 litre. At Rynkeby, the concentrates are diluted to match the original concentration again, i.e. 5/6 litre of water is added to the 1/6 litre concentrate. The same strength of apple and other fruit/vegetable concentrates as for orange juice concentrate has been assumed. To have 1 kg concentrated raw juice at strength 6, approximately 5 kg water needs to be dried off the raw non-concentrated (NFC) juice.

When citrus peels and apple pomace are used animal feed, the by-product goes into the generic markets for feed protein and feed energy. Before the by-products are used as animal feed, they are dried. According to McGregor (2000), the protein and feed energy content of citrus by-products are 0.069 kg/kg dm and 7.91 MJ NE_l/kg dm. The inventory data for feed protein and feed energy are described in (Dalgaard et al. 2015b). For every 1 kg dry matter input of fruit, there is roughly an output of 0.67 kg juice (dm) and 0.33 kg by-product (dm) that is used as animal feed. The by-products have an average dry matter content at 20%, and they are dried to approximately 90% dm before used as animal feed. This means that the 0.33 kg dm by-product is associated with the drying of 1.3 kg water.

When the juice concentrate is produced, heat is needed to dry out the water. No information on the fuel mix at the raw juice producers is available. The global average fuel mix used by industries has been used as a representative figure, see **Table 5.2**.

TABLE 4.1: FUEL MIX (ON ENERGY CONTENT BASIS) IN WORLD AVERAGE INDUSTRIES IN 2009. THE DATA ARE OBTAINED FROM (IEA 2011).

Country	Fuel source			
	Coal	Fuel oil	Natural gas	Total
World	46%	23%	31%	**100%**

The energy use (fuel inputs) for drying can be calculated as (Tsotsas and Mujumdar 2012):

1. **Evaporation load:** $E_v = m_{water}\,\Delta H = m_{water}\,(H_2 - H_1)$ where H_1 and H_2 are the enthalpy of the water before and after drying respectively. Assuming that the water in the raw material has initial temperature at 20°C (pressure 1 atm =1.0142 bar) and that the evaporated water is saturated vapour, i.e. no over-drying and that it has a temperature at 100°C (pressure 1 atm =1.0142 bar), then we have: and that $E_v = m_{water}$ (2.2564 MJ/kg – 0.0838 MJ/kg), i.e. the evaporation load for 1 kg water is 2.34 MJ. The specific enthalpies for liquid water and steam are obtained from the Engineering Toolbox (2013) and eFunda (2013) respectively.
2. Plus losses related to the drying process, i.e. exhaust heat and heat losses from dryer body etc.
3. Plus losses related to drier energy supply, i.e. steam generation efficiency, steam leaks etc.

No specific data on juice drying has been identified. Therefore, drying data for peels are based on data for grain drying. Data on the energy use for drying of grains are shown in **Table 4.2**.

TABLE 4.2: ENERGY USE FOR DRYING.

Data source	Fuel use (MJ) per kg removed water	Electricity use (kWh) per kg removed water
(Brinker and Johnson 2010): Pulaski Continuous cross flow	4.33 MJ/kg	0.0123 MJ/kg
(Brinker and Johnson 2010): Marshfield cross flow	2.42 MJ/kg	0.0159 MJ/kg
Applied in this study	**3.37 MJ/kg**	**0.0141 kWh/kg**

TABLE 4.3: LCI DATA OF RAW MATERIALS FOR RYNKEBY: RAW JUICE.

Flow	Unit	Juice, NFC	Juice, concentrate	LCI data
Reference flow				
Raw juice, NFC (10% dm)	kg	1		Reference flow
Raw juice, concentrate (60% dm)	kg		1	
By-product outputs				
Citrus peel/apple pomace for animal feed	kg	0.05	0.3	See text above the table.
Raw materials				
Crops n.e.c. (100% dm)	kg	0.15	0.9	Dataset from FORWAST. FORWAST is described in **section 4.1.**
Other inputs				
Fruits and vegetables, processed (deleted inputs of energy, raw materials and emissions) (100% dm)	kg	0.1	0.6	Modified dataset from FORWAST. FORWAST is described in **section 4.1.**
Drying, dried off water	kg	1.3	6.3	See **Table 4.1** and **Table 4.2**

4.2.10 Sugar
The data set for sugar is described in Dalgaard and Schmidt (2012). These LCI data are available in both a consequential and an attributional version.

4.2.11 Other 'non-milk based products'
In Arla's accounting system, this category covers e.g. juice, cocoa, vitamins, muesli etc. Since the majority is juice, the same data set as for 'Fruits-jam' above has been used: FORWAST: 'EU27 _21 Fruits and vegetables, processed' (see **section 4.1**). Average dry matter at 30% has been assumed. Except from the electricity mix and inclusion of iLUC, there is no difference for the consequential and attributional version of the used LCI data.

4.2.12 Packaging materials
Packaging materials include plastics, paper, glass, steel and aluminium. The LCI data for the modelling of these materials are listed below. The listed activity names refer to the datasets in ecoinvent v3.

- **LDPE:** 'Polyethylene, low density, granulate {GLO}| market for' (ecoinvent 2014) plus services add-on (see **section 4.3**).
- **PP:** 'Polypropylene, granulate {GLO}| market for' (ecoinvent 2014) plus services add-on (see **section 4.3**).
- **HDPE:** 'Polyethylene, high density, granulate {GLO}| market for' (ecoinvent 2014) plus services add-on (see **section 4.3**).
- **PS:** 'Polystyrene, expandable {GLO}| market for' (ecoinvent 2014) plus services add-on (see **section 4.3**).
- **PET:** 'Polyethylene terephthalate, granulate, bottle grade {GLO}| market for' (ecoinvent 2014) plus services add-on (see **section 4.3**).
- **PA:** 'Nylon 6 {GLO}| market for' (ecoinvent 2014) plus services add-on (see **section 4.3**).
- **EVOH:** 'Ethylene vinyl acetate copolymer {GLO}| market for' (ecoinvent 2014) plus services add-on (see **section 4.3**).
- **Paper:** 'EU27 _35 Paper and paper products' (FORWAST, see **section 4.1**)
- **Glass:** 'EU27 _45 Glass, mineral wool and ceramic goods, virgin' (FORWAST, see **section 4.1**).
- **Steel:** 'EU27 _61 Iron, after first processing' (FORWAST, see **section 4.1**).
- **Aluminium:** 'EU27 _62 Aluminium, after first processing' (FORWAST, see **section 4.1**)

4.2.13 Water
Tap water in the FORWAST database is accounted in monetary unit at basic prices (EUR2003). For the modelling, it is needed to model a specific amount of tap water in physical unit (litre). According to GEUS (2005), the total water extraction by the water extraction industry (not including private extraction and farmer's extractions for irrigation) was 400 million m^3 in 2003. According to the FORWAST database, the supply of water by the water extraction industry in 2003 was 428 million DKK (basic prices), hence the price is 1.07 EUR/m^3. The conversion from EUR2003 to DKK2003 is done by multiplying by 7.431 DKK2003/EUR2003 (Eurostat 2015c). Hence, to convert the reference flow of 1 EUR2003 to m^3, we multiply by (428 million DKK2003/400 million m^3) / 7.431 DKK2003/EUR2003 = 0.144 m^3/EUR2003.

4.3 Services
All inputs of services to Arla's operations as well as other stages in the life cycle are modelled using input-output data (see **section 4.1**). In cases where LCI datasets, which do not include services, have been used, e.g. when using data from the ecoinvent database, then the average service inputs to the relevant sector has been added to the data set. These data have been obtained from the FORWAST input-output database.

4.4 Electricity data sets

Electricity is used in most activities of the product systems. Generally, electricity at medium voltage is used in all activities. This includes production and high and medium voltage grid. Grid losses are considered. The original FORWAST database operates with average electricity mixes as of 2003. This has been replaced with other data to comply with applied modelling assumptions in the current study (see **section 4.1**).

The methodology for the inventory of electricity is described in Muñoz et al. (2015). This is an electricity life cycle inventory project, which allows for application of different modelling assumptions:

1. Consequential, ecoinvent v3 (based on the ecoinvent database)
2. Consequential future (based on data for 2012-2020)
3. Consequential historical (based on data for 2000-2012)
4. Consequential coal (100% coal)

In the modelling of electricity, the consequential (future) scenario is used. In the consequential (future) scenario, the affected suppliers are identified as the proportion of the growth for each supplier during the period 2012-2020. The electricity generation in 2020 is identified by use of energy plans/outlooks. The methodology for inventorying electricity is further described in (Muñoz et al. 2015; Schmidt et al. 2011). The latter can be freely accessed here: http://www.lca-net.com/projects/electricity_in_lca/.

The applied electricity mixes of the consequential (future) scenario for DE, DK, SE and UK are shown in **Table 4.4** below. The average electricity mixes used in the attributional results are based on the attributional version of the ecoinvent database (ecoinvent 2014). The mixes represent the supply in the counties, i.e. national supply plus import.

In the current study, country/region-specific data following the methodology referred to above are used for:

- Foreground system: This includes electricity used directly by dairy farms, Arla sites, retail, households and waste treatment:
  - Germany, Denmark, Finland, Sweden and United Kingdom.
  - Other countries are modelled using data for EU27.
- Background system: This includes electricity used anywhere else in the product system, i.e. in the used databases:
  - FORWAST database: Denmark, EU27, Rest-of-world
  - Ecoinvent database: BE, BR, CH, CN, CZ, DE, DK, FI, FR, UK, ID, IN, MX, MY, PL, SE, US. Electricity in all other countries is modelled using the default electricity mixes in ecoinvent.

TABLE 4.4: APPLIED ELECTRICITY MIXES FOR THE CONSEQUENTIAL RESULTS. ELECTRICITY MIXES ARE SHOWN FOR THE MOST IMPORTANT COUNTRIES IN THE STUDY. THE DATA ARE BASED ON MUÑOZ ET AL. (2015).

Electricity source	Germany	Denmark	Sweden	United Kingdom
Coal	0%	0%	0%	0%
Oil	0%	0%	0%	0%
Gas	19%	0%	0%	31%
Biomass	12%	5%	29%	12%
Nuclear	0%	0%	22%	0%
Hydro	4%	0%	0%	0%
Wind	55%	81%	48%	52%
Geothermal	1%	0%	0%	0%
Solar	11%	13%	0%	2%
Marine	0%	0%	0%	4%
Total	**100%**	**100%**	**100%**	**100%**

4.5 District heating

District heating is modelled using the data in Schmidt and Dalgaard (2012b, section 6.2). These data represent district heating in Denmark based on wood chips burned in combined heat and power plant (CHP). The efficiency of the CHP is 59% heat and 28% electricity. The LCI data for wood chips and combustion hereof are documented in Schmidt et al. (Muñoz et al. 2015; Schmidt et al. 2011). The data from Schmidt (2012) are supplemented with services as described in **section 4.3**.

Since the use of district heating at Arla Foods is generally insignificant compared to the use of electricity and fuels, LCA data for Denmark is use as representative for district heating in all countries.

4.6 Fuel and combustion datasets

The emissions related to the production and combustion of fuels are described below. Whenever fuel is needed in an LCA activity this is modelled using the data for coal, natural gas and fuel oil from FORWAST (EU27 data).

The used data for converting between kg and MJ as well as emission factors are specified in **Table 4.5**.

When using biogas, it has been assumed that this is based on wastes such as manure and industrial and municipal organic wastes. This implies that the availability of biogas is determined by the amount of waste sent to treatment in a biogas plant, and thereby the biogas is a by-product. Therefore, the use of biogas will affect the marginal use of biogas, which is assumed to be for district heating. This means that the use of 1 MJ biogas (without burning it) will have the effect that 1 MJ more wood chips is burned and 1 MJ less biogas in a CHP. The data for the production and combustion of wood chips are obtained from Muñoz et al. (2015) and the emissions from burning biogas are given in **Table 4.5** below.

TABLE 4.5: EMISSION FACTORS FOR STATIONARY COMBUSTION IN INDUSTRY (CRF CODE: 1A2 A-F, SEE NIELSEN ET AL. (2013).

Fuel	Unit	Coal	Natural gas	Liquefied petroleum gas	Gas oil	Fuel oil	Biogas	Wood pellets	References
Fuel properties									
Heating value (lower)	MJ/kg	24.4	49.4	46.0	42.7	40.7	20.5	17.5	(Nielsen et al. 2013, p 845) (Schmidt and Brandão 2013)
Heating value (lower)	MJ/Nm3		39.5				22.7		Natural gas: Nielsen et al. (2013, p 845), biogas (ecoinvent 2014 specific activity, see **)
Density	kg/Nm3		0.80				1.11		Natural gas ("Engineering tool box" 2015), biogas (Naskeo Environment 2015)
Emission factors									
CO_2 (fossil)	kg/GJ	94.73	56.97	63.1	74.00	74.00			(Nielsen et al. 2013, p 847)
CH_4 (fossil)	kg/GJ	0.0014	0.0014	0.002	0.002	0.0013			(Nielsen et al. 2013, p 849-851)
CH_4 (biogenic)	kg/GJ						0.005	0.015	(Nielsen et al. 2013, p 849-851)
N_2O	kg/GJ	0.0014	0.001	0.0006	0.0021	0.005	0.0001	0.004	(Nielsen et al. 2013, p 852-854)
SO_2	kg/GJ	0.574	0.0003	0.00013	0.023	0.344	0.025	0.025	(Nielsen et al. 2013, p 852-854)
NO_x	kg/GJ	0.095	0.042	0.096	0.065	0.136	0.028	0.090	(Nielsen et al. 2013, p 855-858)
NMVOC	kg/GJ	0.010	0.002	0.005	0.005	0.0008	0.002	0.010	(Nielsen et al. 2013, p 855-858)
CO	kg/GJ	0.010	0.028	0.025	0.0030	0.0028	0.036	0.240	(Nielsen et al. 2013, p 855-858)
Particulates <2.5	kg/GJ	0.020	0.000070	0.00035*	0.00035*	0.00035		0.0338	(ecoinvent 2014 specific activities see **)
Particulates <10	kg/GJ	0.040						0.00187	

* Assumed to be same as fuel oil.

** References to ecoinvent data sets:

- Coal: 'Heat, central or small-scale, other than natural gas {Europe without Switzerland}| heat production, hard coal briquette, stove 5-15kW' (ecoinvent 2014).
- Natural gas: 'Heat, central or small-scale, natural gas {Europe without Switzerland}| heat production, natural gas, at boiler atm. low-NOx condensing non-modulating <100kW' (ecoinvent 2014).
- Fuel oil: 'Heat, central or small-scale, other than natural gas {Europe without Switzerland}| heat production, light fuel oil, at boiler 100kW condensing, non-modulating' (ecoinvent 2014).
- Biogas: 'Biogas {DK}| heat and power co-generation, gas engine' (ecoinvent 2014).
- Wood pellets: 'Heat, central or small-scale, other than natural gas {RoW}| heat production, wood pellet, at furnace 300kW, state-of-the-art 2014' (ecoinvent 2014).

4.7 Transport

Whenever possible, transport is modelled using data from ecoinvent:

- **Road transport:** Data set from ecoinvent: 'Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4' (ecoinvent 2014),
- **Rail transport:** Data set from ecoinvent: 'Transport, freight train {Europe without Switzerland}| electricity' (ecoinvent 2014),
- **Air freight:** Data set from ecoinvent: 'Transport, freight, aircraft {RER}| intercontinental' (ecoinvent 2014),
- **Ship transport:** Data set from ecoinvent: 'Transport, freight, sea, transoceanic ship {GLO}| processing' (ecoinvent 2014).

To obtain completeness in the LCI data, services need to be added to the ecoinvent data. Input-output data are used for this purpose. The FORWAST database contains information on the use of services per EUR transport services (separate data for road, rail and water transport). In order to link the ecoinvent data (reference flow = tkm) and FORWAST data (reference flow = EUR), we need to know the price of transport. This is obtained as 0.15 EUR/tkm for heavy duty vehicles, 0.11 EUR/tkm for rail transport, 0.75 EUR/tkm for air freight, and 0.009 EUR/tkm for ship transport (Schade et al. 2006, table 6).

Arla uses different fuels for transport, see **Table 4.6**. Since the uses of liquefied natural gas (LNG), liquefied bio methane (LBM) and petrol are very small compared to diesel, rapeseed methyl ester (RME), and BIO+, it has been decided to model this as if it was diesel. For BIO+ (see footnote 3), it has not been possible to identify good LCI data for hydrogenated vegetable oil (HVO). Therefore, HVO is represented by RME.

The combustion of all fuels is represented by combustion data in the following ecoinvent data set: 'Transport, freight, lorry 16-32 metric ton, EURO4 {RER}| transport, freight, lorry 16-32 metric ton, EURO4'. For biofuels, fossil CO_2 is eliminated.

TABLE 4.6: APPLIED LCI DATA FOR THE PRODUCTION OF DIFFERENT TRANSPORT FUELS.

Fuel	Share (by energy content)	Applied placeholders for the different fuels	Applied LCI data
Diesel	89%	Diesel	Diesel, low-sulfur (ecoinvent 2014)
Rapeseed methyl ester (RME)	4%	RME	Vegetable oil methyl ester {RoW}| esterification of rape oil (ecoinvent 2014). The input of crude rapeseed oil is based on Dalgaard and Schmidt (2012) and Schmidt (2015). The rapeseed dataset is linked to the iLUC model (see **section 4.9**)
BIO+ [3]	6%	73% diesel 27% RME	See above.
Liquefied natural gas (LNG)	<1%	Diesel	
Liquefied bio methane (LBM)	<1%	Diesel	
Petrol	<1%	Diesel	

It should be noted that transport data are needed at two different levels. The LCI data for the first level must be limited to avoid double counting:

1. Arla's internal transport includes:
   - Supply of fuel
   - Fuel combustion emissions
   - Non-combustion emissions (brake, tire and road wear emissions)
   - Infrastructure (construction and maintenance of roads)
2. All other transport includes:
   - Supply of fuel
   - Fuel combustion emissions
   - Non-combustion emissions (brake, tire and road wear emissions)
   - Lorries (production, maintenance and disposal)
   - Services, i.e. inputs related to the administration of transport supplier companies (e.g. hotels & restaurants, communication, marketing, computer related services, real estate services)
   - Infrastructure (construction and maintenance of roads)

For Arla's internal transport, the production and maintenance of lorries as well as associated services should not be included. This is because these spending are accounted for somewhere else, i.e. by taking into account the explicit spending of lorries and associated services.

4.8 Materials for treatment (waste)

Generally, waste treatment and recycling has been modelled using the FORWAST database (see **section 4.1**). In **Table 4.7** below, the different waste flows from Arla sites are listed, and the relevant information for LCI modelling is provided. The reference flows of the LCI datasets in the FORWAST database are in dry matter mass. Therefore, it is necessary to know the dry matter percentage of the waste flows. No data are available for this, therefore this has been estimated. Some of the data from Arla on waste fractions do not specify the type of waste. In order to be able to model the treatment with the FORWAST database, the composition of these mixed waste flows is estimated.

[3] BIO+ is a blend containing 73% diesel, 20% hydrogenated vegetable oil (HVO), and 7% rapeseed methyl ester (RME).

TABLE 4.7: MATERIALS FOR TREATMENT SUPPLIED BY ARLA SITES: WASTE TYPES AND PROPERTIES, WASTE TREATMENT AND APPLIED LCI DATA.

Waste flow	Dry matter %	Treatment	Composition (only for mixed fractions) Fraction	Share	LCI data
Organic waste	50%	Biogas			EU27 109 Waste treatment, Biogasification of food waste
		Composting			EU27 112 Waste treatment, Composting of food waste
		Land application			EU27 129 Waste treatment, Land application of compost
		Other			EU27 101 Waste treatment, Incineration of waste, Food
Sludge	20%	Biogas			EU27 111 Waste treatment, Biogasification of sewage sludge
		Composting			EU27 112 Waste treatment, Composting of food waste
		Land application			EU27 129 Waste treatment, Land application of compost
		Other			EU27 101 Waste treatment, Incineration of waste, Food
Plastics	100%	Recycling			EU27 _42 Recycling of plastics basic
Paper and cardboard	90%	Recycling			EU27 _34 Recycling of waste paper
Glass	100%	Recycling			EU27 _46 Recycling of glass, mineral wool and ceramic goods
Metals	100%	Recycling	Steel	45%	EU27 _54 Recycling of iron basic
			Aluminium	45%	EU27 _56 Recycling of aluminium basic
			Copper	5%	EU27 _58 Recycling of copper basic
			Other metals	5%	EU27 _60 Recycling of metals basic, n.e.c.
Other	80%	Recycling	Inert waste	90%	EU27 _50 Recycling of concrete, asphalt and other mineral products
			Wood	10%	EU27 __8 Recycling of waste wood
Mixed waste	90%	Incineration	Organic waste	20%	EU27 101 Waste treatment, Incineration of waste, Food
			Plastics	20%	EU27 103 Waste treatment, Incineration of waste, Plastic
			Paper	20%	EU27 102 Waste treatment, Incineration of waste, Paper
			Glass	20%	EU27 105 Waste treatment, Incineration of waste, Glass/inert
			Metals	20%	EU27 104 Waste treatment, Incineration of waste, Metals
		Landfill	Organic waste	20%	EU27 116 Waste treatment, Landfill of waste, Food
			Plastics	20%	EU27 118 Waste treatment, Landfill of waste, Plastic
			Paper	20%	EU27 117 Waste treatment, Landfill of waste, Paper
			Glass	20%	EU27 123 Waste treatment, Landfill of waste, Glass/inert
			Metals	20%	EU27 119 Waste treatment, Landfill of waste, Iron
Hazardous waste	50%	Recycling			EU27 108 Waste treatment, Incineration of waste, Oil/Hazardous waste
		Incineration			EU27 108 Waste treatment, Incineration of waste, Oil/Hazardous waste
		Landfill			EU27 127 Waste treatment, Landfill of waste, Oil/Hazardous waste
Wastewater	0.17%*	Recipient			EU27 114 Waste treatment, Waste water treatment, food
		Waste water treatment			EU27 114 Waste treatment, Waste water treatment, food
		Land application			EU27 129 Waste treatment, Land application of compost

* The DM% of wastewater has been estimated based on COD concentrations in waste water from three dairy sites in Denmark and Sweden (Korsström and Lampi 2001) and by roughly assuming that 1 kg DM ~ 1 kg COD (based on comparison of various data sources).

4.9 Indirect land use changes (iLUC)

The iLUC model described in **section 3.2** is used to include iLUC effects for all LCA activities in the product system that occupy land. The methodological framework of the model is described in Schmidt et al. (2015), and the data used for populating the model framework are documented in Schmidt and Muñoz (2014). Compared to the data described in Schmidt and Muñoz (2014), the below ground carbon stock of cropland has been updated to 20.7 t C/ha (53% of initial land: forest) so that it is in accordance with (IPCC 2006b) and (IPCC 2006a). Further, it should be noted that the fertiliser input to intensification is based on ecoinvent v3 (ecoinvent 2014) dataset: 'Nitrogen fertiliser, as N {GLO}| market for'. Due to an error in the fertiliser mix in this ecoinvent activity, this has been corrected to 75% urea, 16% ammonium nitrate, 4% calcium ammonium nitrate, 5% ammonium sulphate. This mix represents the global average in 2012.

5. Life cycle inventory: Arla

5.1 Structure of the inventory of Arla

Arla Foods is divided into 10 business groups. Under each business group, there are a number of profit centres (processing, logistics and administrative units). There are 99 profit centres in Arla Foods: 75 processing food, 19 in logistics and 5 administrative sites.

In **Table 5.1**, a list of the different data sets provided by Arla Foods is shown. Some data are available at the level of profit centres and other data are available at the level of business groups.

TABLE 5.1: DATA SETS PROVIDED BY ARLA FOODS. THE UNITS OF THE DATASETS ARE GIVEN IN BRACKETS IN THE COLUMN IN THE MIDDLE.

Dataset	Data categories	Available for
1. Sales and direct spends and waste flows (physical data) (all excl. Rynkeby)	• Sales of products (Fresh dairy products, butter and Spread, cheese, powder, non-milk based products, former Foodstuff = animal feed, whey and other = animal feed) (tonne) • Raw materials (dairy products, salt, fruits-jam, sugar, veg. oil, other) (tonne) • Fuels (gas oil, fuel oil, natural gas, liquefied petroleum gas, biogas, biomass). Fuels for internal transport are included here. (tonne) • Energy (electricity and district heating) (MWh) • Water (internal/external borehole) (m^3) • Wastes (product waste, sludge, plastics, paper, glass, metals, other, hazardous, waste water) to different treatments (tonne)	93 profit centres (75 processing units and 19 logistic units)
2. Sales and direct spends and waste flows (physical data) (only Rynkeby)	• Sales of products: Fruit juice (tonne) • Raw materials: – Juice (orange, apple, citrus other, veg/fruit) (tonne) – Concentrates (orange, apple, citrus other, veg/fruit) (tonne) – Other raw materials (aroma/functional, sugar) (tonne) • Fuels (natural gas, liquefied petroleum gas) (tonne) • Energy (electricity and district heating) (MWh) • Water (external borehole) (m^3) • Wastes (product waste, sludge, plastics, paper, glass, metals, other, hazardous, waste water) to different treatments	1 profit centre (Rynkeby)
3. Packaging (physical data)	• 9 types of plastics (tonne) • 3 types of paper/cardboard (tonne) • Glass (tonne) • Steel (tonne) • Aluminium (tonne)	94 profit centres (76 processing units and 19 logistic units). No packaging use for logistic units.
4. External transport (physical data)	• Lorry (tonne CO_2-eq.) • Train (tonne CO_2-eq.) • Ship (tonne CO_2-eq.) • Air (tonne CO_2-eq.)	7 business groups
5. All spends (economic data)	• Three different levels of suppliers – 10 sourcing families (EUR 2014) – 101 sourcing head groups (EUR 2014) – 368 sourcing groups (EUR 2014)	10 business groups

In some cases the datasets in **Table 5.1** are overlapping, i.e. to avoid double counting, some modifications are needed. This is relevant in the following two cases:

- Dataset 5 includes all spends while dataset 1, 2, 3 and 4 only includes a subset hereof. Priority has been given to the data in physical units in dataset 1, 2, 3 and 4. All entries in dataset 5, which are overlapping with one of the other datasets, have been deleted.
- Dataset 1 includes the supply and use of semi-manufacture/products for packaging between Arla profit centres. These flows have been eliminated.

Some of the datasets in **Table 5.1** are reported in incompatible units with the current study, e.g. all transport needs to be accounted for in tkm (and not already calculated impacts as in dataset 4). Whenever relevant, the units have been converted. This is described in the following sections in **chapter 5**.

As indicated in **Table 5.1**, some data are available at the level of profit centres (individual sites), whereas other data are available at the level of business groups (many individual sites). Generally, the business groups mainly include profit centres from the same country, but most of them also have some profit centres in other countries. The main country of each business centre is specified in **Table 5.2**. Country specific data are used for this country for all data, which are only available at the business group level.

TABLE 5.2: BREAKING DOWN OF THE ARLA ACTIVITIES INTO 10 BUSINESS GROUPS AND THEIR MAIN LOCATION (COUNTRY).

Arla Business Groups	Location
Arla Food Ingredients (AFI)	DE
Consumer Denmark (CDK)	DK
Consumer Central Europe (CCE)	DE
Consumer International (CIN)	GLO
Consumer Finland (CFI)	FI
Consumer Sweden (CSE)	SE
Consumer United Kingdom (CUK)	UK
Global Category Operation (GCO)	DK*
Subsidiaries	DK
Other	DK

* The location is global, but since most sites are in Denmark, this location has been chosen as representative.

5.2 Sales

Table 5.3 shows the total sales of Arla Foods 2014, i.e. the product portfolio. Hence, the amounts of products given here corresponds to the functional unit, described in **section 2.3**. For each of the products, a use and end-of-life stage is defined (see **chapter 2.2**) except for by-products (animal feed), see **section 2.3**.

TABLE 5.3: SHARES OF THE DIFFERENT PRODUCTS AND BY-PRODUCTS IN ARLA'S PRODUCT PORTFOLIO.

Arla products	Production in 2014 (tonne)	Share
Main products		
Fresh dairy products	5,551,000	62%
Cheese	680,000	8%
Powder	501,000	6%
Whey powder	493,000	5%
Butter and Spread	274,000	3%
Non milk based products	181,000	2%
By-products (animal feed)		
Whey	1,232,000	14%
Former Foodstuff	87,000	1%

5.3 Raw materials

In **Table 5.4** below, Arla's use of raw materials in 2014 is summarised. The categories of raw materials follow the ones used in the description of the LCI data in **section 4.2**. Spatial differentiation is given for milk-based products.

TABLE 5.4: USE OF RAW MATERIALS AT ARLA FOODS. UNIT: TONNE.

Raw materials	DE	DK	SE	UK	Other	Total
Raw milk	2,417,000	4,838,000	2,091,000	3,684,000	591,000	**13,621,000**
Butter	0	0	0	0	6,200	**6,200**
Cheese	0	2,100	0	0	5,800	**7,900**
Powder (milk)	0	14,100	300	900	2,700	**18,000**
Whey (5.2% dm)	911,000	331,000	0	0	971,000	**2,213,000**
Salt						**15,300**
Fruits-jam (30% dm)						**19,600**
Sugar						**18,600**
Vegetable oil						**66,400**
Non-milk based products (30% dm)						**117,000**

5.4 Packaging use

The use of packaging at Arla Foods in 2014 is summarised in **Table 5.5**. LCI data for packaging materials are described in **section 4.2**.

TABLE 5.5: USE OF PACKAGING MATERIALS AT ARLA FOODS IN 2014.

Packaging material	Amount (tonne)
Plastics: LDPE	25,000
Plastics: PP	19,000
Plastics: virgin HDPE	35,000
Plastics: recycled HDPE	7,000
Plastics: PS	6,000
Plastics: virgin PET	5,000
Plastics: recycled PET	3,000
Plastics: PA	1,000
Plastics: EVOH	500
Paper: Carton for milk, cream etc.	71,000
Paper: Other	5,000
Paper: Cardboard, corrugated cardboard	69,000
Glass	23,000
Steel	16,000
Aluminium	3,000
Total	**289,000**

5.5 Energy use

The use of energy at Arla Foods in 2014 is summarised in **Table 5.6**. LCI data for energy are described in **section 4.4** and **4.5**. It should be noted that the specified energy is net energy use, i.e. used energy minus sold energy (by-products).

TABLE 5.6: USE OF ENERGY AT ARLA FOODS IN 2014: ELECTRICITY, FUELS AND DISTRICT HEATING. THE LOCATION IS SPECIFIED FOR ELECTRICITY.

Energy use	Amount (MWh)
Electricity	
DE	117,000
DK	300,000
FI	15,000
SE	240,000
UK	208,000
EU27 (and minor other)	63,000
Total	**943,000**
Fuels	
Gas oil	41,000
Fuel oil	100,000
Natural gas	2,012,000
Liquified Petroleum Gas	7,000
Biogas	27,000
Biomass e.g. woodchips	134,000
Total	**2,321,000**
District heating	
District heating	**47,000**

5.6 Transport

Arla accounts for the GHG emissions related to transport by the lorries operated by Arla (internal transport) and to purchased transport services by Arla (external transport). Internal transport includes collection of milk from dairy farms (except in the Netherlands) and transport of intermediate products between production sites. External transport includes outbound transport of dairy products in Denmark, Sweden, and United Kingdom as well as some transport of intermediate products between sites. Both internal and external transport are included as part of the inventory for the dairy life cycle stage. Since external transport includes some outbound transport, this should ideally be accounted for under the downstream activities (**chapter 6**). However, the part of external transport that concerns outbound transport cannot be separated out, hence it is included here. Outbound transport of Arla products in other countries than Denmark, Sweden and United Kingdom are included as part of the downstream activities in **section 6.1**.

5.6.1 Internal transport

The use of fuels for internal transport is shown in **Table 5.7**. It should be noted that the fuel use below is 416 m^3 higher than in the original data from Arla. The original data were lacking fuel for the collection of milk from dairy farms in the Netherlands. The average fuel use (m^3) per tonne milk for milk collection in Denmark was calculated as 0.00167 m^3/tonne milk[4]. It was assumed that this factor is a reasonable estimate for the Netherlands. Multiplying this factor by the volume of raw milk collected in the Netherlands, we obtained a volume of 416 m^3 fuel.

TABLE 5.7: FUEL USE FOR ARLA'S INTERNAL TRANSPORT 2014. THE ORIGINAL DATA IN M3 ARE CONVERTED TO GJ USING THE CONVERSIONS IN **APPENDIX 1: FUEL AND DAIRY PRODUCT PROPERTIES**.

Fuels for internal transport	Fuel use (m^3)	Fuel use (GJ)
Diesel	55,204	1,979,570
Rapeseed methyl ester (RME)	2,414	79,923
BIO+	3,469	122,660
Liquefied natural gas (LNG)	429	8,707
Liquefied bio methane (LBM)	233	5,127
Petrol	651	20,014

The inventory data for fuels only distinguish diesel and RME, the fuels in **Table 5.7** need to be classified into these categories. In **Table 5.8** below, this is done on the basis of energy content. The inventory data for transport are in units of tkm (see **section 4.7**). Therefore, the amounts diesel and RME in units of GJ in **Table 5.8** are converted to tkm. According to the ecoinvent data for road transport (see **section 4.7**), the diesel use is 0.0374 kg/tkm. Using the data in '**Appendix 1: Fuel and** dairy product properties' the 0.0374 kg diesel/tkm can be converted to 1.61 MJ/tkm.

4 According to **Table 5.9**, the transport in tkm per kg CO_2 for road transport is 0.131 kg CO_2/tkm (CO_2 from fuel+combustion). In the LCI dataset for road transportation (**section 4.7**) it can be seen that the fuel use is 0.0374 kg diesel/tkm. Hence 1 t CO_2 corresponds to 0.285 kg diesel/kg CO_2. This can be converted to 0.343 m^3 diesel/t CO_2. The total fuel+combustion CO_2 from milk collection in Denmark is reported by Arla as 23,484 t CO_2. Hence, the fuel consumption can be calculated as 8,058 m^3. The total use of raw milk in Denmark is 4,837,542 tonne. Hence, the average fuel use per tonne milk collection is 0.00167 m^3/tonne milk.

TABLE 5.8: FUEL USE FOR ARLA'S INTERNAL TRANSPORT 2014. THE ORIGINAL DATA IN M^3 ARE CONVERTED TO GJ USING THE CONVERSIONS IN **APPENDIX 1: FUEL AND DAIRY PRODUCT PROPERTIES**.

Fuels for internal transport	Fuel use (GJ)	Fuel use reclassified (GJ)	Transport (tkm)	Applied LCI data
Diesel	1,979,570	2,102,959	1,303,109	See section 4.7
Rapeseed methyl ester (RME)	79,923	113,041	70,046	See section 4.7
BIO+[5]	122,660			
Liquefied natural gas (LNG)	8,707			
Liquefied bio methane (LBM)	5,127			
Petrol	20,014			
Total	**2,216,000**	**2,216,000**		

5.6.2 External transport

External transport includes road, rail, air and ship transport. In Arla's environmental accounting system, external transport is accounted for in units of tonne CO_2-eq. These emissions are calculated by Arla based on reported information by the individual transport providers, and the CO_2-eq. refer to the production of fuels/electricity and fuel combustion emissions. In order to be able to achieve the same level of completeness (cut-off criterion and number of included emissions) in the LCI data for external transport as described in **section 4.7**, the amount of fuel + combustion CO_2-eq. per tkm is registered in the datasets in **section 4.7**, and the reported CO_2 by Arla is scaled to fit with the equivalent tkm.

According to the transport datasets in **section 4.7**, the CO_2-eq. emissions from direct combustion and fuel production are 0.131 kg CO_2-eq./tkm for diesel and 0.103 kg CO_2-eq./tkm for RME. For external transports, a fuel mix of 93% diesel and 7% RME is assumed to be representative (Flysjö 2015). Hence the average emissions per tkm are 0.129 kg CO_2-eq./tkm. The total reported tonne CO_2-eq. by Arla is divided by the 0.129 kg CO_2-eq./tkm to calculate the required tkm from the ecoinvent datasets to arrive at the same CO_2-eq. from direct combustion and production of fuel as reported by Arla.

TABLE 5.9: ARLA'S EXTERNAL TRANSPORT.

Transport mode	Fuel+combustion CO_2 in transport LCI data (section 4.7) (kg CO_2/tkm)	Reported fuel+ CO_2 (tonne CO_2)	Transport (tkm)	Applied LCI data
Road	0.129	158,149	1,229,712	See **section 4.7**
Rail	0.0204	143	6,995	
Air	0.999	4,865	4,871	
Ship	0.00879	33,765	3,842,027	

5 BIO+ is a blend containing 73% diesel, 20% hydrogenated vegetable oil (HVO), and 7% rapeseed methyl ester (RME).

5.7 Wastes to treatment

The amounts of wastes and wastewater to treatment at Arla Foods in 2014 are summarised in Table 5.10. LCI data for waste and waste water treatment are described in **section 4.8**.

TABLE 5.10: ARLA'S WASTE TO TREATMENT I 2014.

Material to treatment	Unit	Amount	LCI data
Biogas (product waste)	ton	268,357	See **Table 4.7**
Composting (product waste)	ton	2,458	
Farmland (product waste)	ton	21,135	
Other (product waste)	ton	14,338	
Biogas (sludge)	ton	78,868	
Composting (sludge)	ton	764	
Farmland (sludge)	ton	229,162	
Other (sludge)	ton	7,487	
Plastic materials (recycled)	ton	7,742	
Paper and cardboard (recycled)	ton	7,844	
Glass (recycled waste)	ton	330	
Metals (recycled waste)	ton	2,074	
Other (recycled waste)	ton	4,010	
Waste for incineration	ton	12,195	
Waste for landfilling	ton	2,139	
Recycled (Hazardous waste)	ton	705	
Incineration (hazardous waste)	ton	106	
Land filling (hazardous waste)	ton	311	
Recipient (waste water)*	m3	12,864,508	
External treatment (waste water)*	m3	9,284,665	
Soil (waste water)*	m3	36,300	

* As described in **section 4.8**, it has been assumed that the dry matter content in waste water is 0.17%.

6. Life cycle inventory: Downstream activities

This chapter presents the life cycle inventory of the downstream stage of Arla Foods' products. This includes the following life cycle stages: retail, use and waste treatment, see **Figure 6.1**.

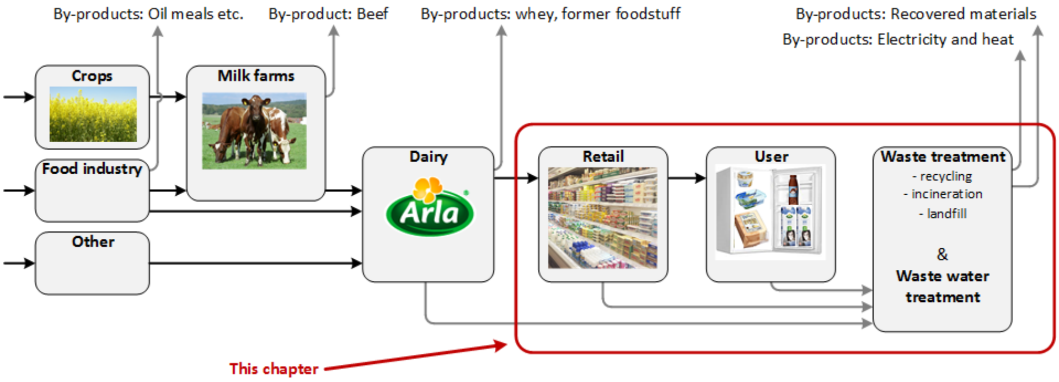

FIGURE 6.1: LIFE CYCLE STAGES INCLUDED IN THIS CHAPTER.

6.1 Transport from Arla Foods to retail

Some of the transport from Arla to retail is accounted for under transport inputs to the dairy processing stage, see **section 5.6**. This is because Arla pays for the majority of the outbound transport in Denmark, Sweden and United Kingdom (Flysjö 2015). For the remaining countries, the transport from Arla to retail is added. According to **section 2.3** on the definition of the functional unit, the downstream stages of by-products sold by Arla Foods are not included. The amount of main products produced outside Denmark, Sweden and United Kingdom in 2014 is 2,270,000 tonne. An average distance of 200 km from dairy to retail has been assumed for these products. Inventory data transport are described in **section 4.7**.

6.2 Retail stage

Arla sells their products in many different countries. Due to lack of data and to the expectation that the spatial difference in impacts is small (compared to the impacts of the upstream system), it has been chosen to model the retail stage based on average European data.

When modelling the retail stage differentiation is made for products that are chilled and not. The amounts of products are summarised in **Table 6.1**.

TABLE 6.1: ARLA'S MAIN PRODUCTS FOR WHICH THE RETAIL STAGE IS INCLUDED. IT IS INDICATED WHICH PRODUCTS REQUIRE CHILLING IN THE RETAIL STAGE. THE DATA IN THIS TABLE ARE DERIVED FROM **TABLE 2.1**.

Arla's main products in 2014	**Amount (tonne wet weight)**	**Chilled**
Fresh dairy products (milk, yogurts, cream…)	5,551,000	Yes
Cheese	680,000	Yes
Powder	501,000	No
Whey powder	493,000	No
Butter and Spread	274,000	Yes
Non milk based products (mainly fruit juice)	181,000	No
Total, chilled	**6,505,000**	**Yes**
Total, non-chilled	**1,175,000**	**No**
Total	**7,680,000**	

To model the retail stage, the following dataset from the FORWAST IO-database (see **section 4.1**) was used: 'Retail trade and repair services'. This activity covers the average retail sector (Eurostat 1996, Nace code 52):

- Retail sale:
  - in non-specialized stores (super markets),
  - of food, beverages and tobacco in specialized stores,
  - pharmaceutical and medical goods, cosmetic and toilet articles,
  - new goods in specialized stores (textiles, clothing, furniture, electrical household appliances, radio and television goods etc.),
  - of second-hand goods in stores,
  - not in stores (mail order houses, stalls and markets)
- Repair of personal and household goods (footwear, electrical household goods, watches etc.)

According to detailed Danish economic accounts (Hafner et al. 2010), 43% of the revenue in this sector in Denmark in 2003 came from 'Retail trade of food etc.' and 'Department stores'. Based on this, it is assessed that the above-mentioned dataset from the FORWAST database is a good representative for retail stores that sell Arla's products. However, to make the activity more representative, the following modifications have been made:

- **Reference flow:** The reference flow of the original dataset refers to EUR margins of the supermarket, and not the total revenue of the sales of products. To be able to link the sales of Arla products, which are accounted for in physical mass unit, with the FORWAST dataset, the unit of the reference flow is firstly converted into EUR sales of products, and secondly into physical unit (mass).
- **Transport:** The inputs of transport are deleted, because this is already included elsewhere in the inventory, see **sections 5.6** and **6.1**.
- **Electricity:** The input of electricity was modified to reflect newer data and to be able to differentiate between products that need cooling and not.

Reference flow: The unit of the reference flow in the original dataset is first converted from EUR2003 margin to EUR2003 sales of products. This is done by dividing by the average margin of the sector. According to Weidema et al. (2005), the average margin in supermarkets in Denmark in 1999 was 20%. This is assumed representative for 2003 and for Europe as well. The next step is to change the unit of the reference flow from EUR2003 to tonne. This is done by using the price of Arla's products. According to **Table 6.1**, the total supply of main products in 2014 were 7,680,000 tonne and according to Arla's financial report (Arla Foods 2015, p 62), the revenue was 10,614 million EUR in 2014. Hence, the price of an average product is 1.38 EUR2014/kg. To be compatible with the FORWAST dataset, this needs to be converted to 2003 currency. This is done by multiplying with 0.777 which is the currency exchange rate between EUR2014 and EUR2003 (Eurostat 2015a). The resulting price in EUR2003/kg is 1.38 EUR2014/kg * 0.777 EUR2003/EUR2014 = 1.07 EUR2003/kg. Summarizing; to convert the reference flow from EUR2003 margin to kg, we multiply with 1 / (20% * 1.07 EUR/kg) = 4.65 kg.

Electricity: The total production, i.e. margin, of the retail sector in Denmark in 2011 was 12,441 million EUR (Statistics Denmark 2015). In the same year, the total electricity use in the retail sector was 2,617 GWh (Statistics Denmark 2015). According to Christensen and Madsen (2001), use of electricity in the retail sector used for cold storage and cool counters was 378 GWh in 1999. Comparing with total data for electricity use in the sector in 1999 (Statistics Denmark 2015), the share of electricity that is used for cold storage and cool counters can be determined as 15%. It is assumed that this share is also representative for 2011 for which the newest data on total electricity use are available. The electricity use (excluding for cooling) in the retail sector can be calculated as (2,617 GWh – 378 GWh)/12,441 EUR = 0.179 kWh/EUR2011 margin. Based on the distribution of sales of products in the retail sector, the share of products (on economic basis) in the retail sector that needs cooling can be estimated as 11% (Statistics Denmark (2015). Hence, the additional electricity use for products that need cooling can be calculated as 378 GWh/(11% of 12,441 EUR) = 0.281 kWh/EUR2011 margin. In order to match the currency of the FORWAST database, the EUR2011 is converted to EUR2003. This is done by multiplying with 0.833 EUR2011/EUR2003 (Eurostat 2015a). The resulting electricity uses for products that need chilling and not are summarised in **Table 6.2**.

TABLE 6.2: SUMMARY OF LIFE CYCLE INVENTORY OF THE RETAIL ACTIVITY FOR THE SALES OF ARLA PRODUCTS CHILLED AND NON-CHILLED. ONLY THE FLOWS, WHICH ARE CHANGED, COMPARED TO THE ORIGINAL FORWAST DATASET ('RETAIL TRADE AND REPAIR SERVICES', EU27) ARE SHOWN HERE.

Unit	Unit	Non chilled	Requiring chilling	Applied LCI data
Output: Reference flow				
Sales of Arla products (retail)	kg WW	4.46	4.46	Reference flow changed from 1 EUR2003 margin to 4.46 kg sold product
Input: Energy use				
Electricity	kWh	0.149	0.382	See **section 4.4.**
Input: Transport				
Land transport	EUR	0	0	Original inputs of transport are eliminated
Air transport	EUR	0	0	
Sea transport	EUR	0	0	

6.3 Use stage: Home transport

According to Weidema et al. (2008, Table 8.10, p.114) the amount of passenger car driving in EU27 is 16.3 vehicle-km/person/day. 18% hereof relates to shopping, and 37% of the shopping relates to food. Hence, the use of passenger car transport for food shopping is 16.3 vehicle-km/person/day * 18% * 37% = 1.09 vehicle-km/person/day. According to Weidema et al. (2005, Table 6.2), the use of food in households in Denmark is 2.62 kg/person/day. This gives an average amount of passenger car transport related to food at 1.09/2.62 = 0.414 vehicle-km/kg food. It can be argued that the determining factor for food shopping is the lifetime of food. Hence, the 1.09 vehicle-km can be allocated to only short-lived food products instead of all food products. Short-lived products are here assumed to be:

- Meat, fish and egg
- Milk, cream, yoghurt etc.
- Fruit and vegetables except potatoes

These products account for 49% of the mass of all food products. Hence, if passenger car transport for food shopping is allocated only to short-lived food products, the transport is 1.09/(2.62*49%) = 0.846 vehicle-km/kg food. We have chosen to use the 0.846 vehicle-km/kg (allocated to short-lived food products) for the consequential version of the modelling and the 0.414 vehicle-km/kg (allocated to all food products) for the attributional version.

Passenger car transport is modelled using the following LCI dataset from ecoinvent (ecoinvent 2014): 'Transport, passenger car, EURO 5 {RER}| market for'. To this is added services obtained from the FORWAST dataset 'Motor vehicles and trailers'. The amount of car (EUR/km) used for the service add-on are estimated as kg car/km (from the above-mentioned ecoinvent dataset as 0.0107 kg/km) multiplied with the price per kg of an average car. This is estimated as 10,000 EUR/850 kg = 11.8 EUR/kg. Hence, the amount of services per vehicle-km is 0.0107*11.8 = 0.125 EUR/km.

6.4 Use stage: storage, cooking, dishwashing

The handling of dairy products in the household includes cold storage, dishwashing and the complementary purchase of glass, tableware and domestic appliances (refrigerator and dishwasher). To model this step, the activity 'EU27 140 Household use, meals' is used as starting point and modified. The original dataset represents the complete life cycle inventory of food consumption in the EU27 in 2003. The following modifications are made to the dataset:

- **Changing the reference flow**. The original reference flow in EUR is made compatible with the product flows related to the functional unit in the current study, i.e. kg dairy products used by households.
- **Deleting inputs and outputs** that are included at other places in the life cycle inventory. An example is the production of food inputs, which are accounted for in **section 5**.
- **Modifying the inputs of energy for storage in refrigerator and dishwashing**. The original dataset includes all energy related to food storage, preparation and dishwashing for the average of all food and beverage items used in the EU27. This needs to be made specific for dairy products, which require more energy for storage in refrigerator and no energy for preparation compared to average food and drinks.
- **Adding water use**. The original FORWAST dataset does not include water use. This is added.
- **Modifying the amounts of materials for treatment and their type of treatment**. Wastes include packaging wastes (must be matched with inputs of packaging in **section 5.4**), food waste (wasted dairy products), and excretion/urine to waste water treatment. In addition, the methane emissions produced by colonic bacteria for the digestion of dairy products are added.

6.4.1 Reference flow

The original reference flow of the activity 'EU27 140 Household use, meals' in the FORWAST database is EUR. This is changed to the amount (mass) of food product inputs to the households. According to the FORWAST dataset for household use of meals, the total monetary flow is 1184 billion EUR. Based on food balance sheets in FAOSTAT (2015), the total food and beverages consumption in EU27 is identified as 486 million tonne in 2003 (2.7 kg per capita per day). Hence, the reference flow of the activity can be changed to 486 million tonne/1187 billion EUR = 0.41 kg ww food.

6.4.2 Deleting inputs that are included in other parts of the LCI

All inputs and outputs that are included at other places in the life cycle inventory, are deleted from the original dataset in the FORWAST database 'EU27 140 Household use, meals'. This includes:

- Inputs of food products are deleted (included in **section 5**)
- Inputs of retail services (included in **section 6.2**)
- Inputs of fuels, vehicles for transport and related services are deleted (included in **section 6.3**). Also, the emissions relating to the combustion of transport fuels are deleted.
- Emissions related to the combustion of fuels heating (for food preparation) are deleted (this does not relate to dairy products).

6.4.3 Electricity for refrigerator

The electricity use for the storage of dairy products in refrigerator is estimated based on a top-down approach, where it is identified how much electricity is annually used for refrigerators and how much food is stored in refrigerators in households. The electricity use per kg food is calculated as the total electricity use divided by the total food that needs chilling. Data for the EU27 are used as representative for storage of Arla Foods' products stored in refrigerators. The calculation is also performed for Denmark in order to make a sanity check of data.

Denmark: According to Gram-Hanssen (2005, p 19-20), 25% of the electricity use in Danish households in 2000 was used for chilling and freezing of which 50% was used for chilling. In 2003, the total electricity use in Danish households was 10,269 GWh (Energistyrelsen 2004). Hence, the electricity use for storage of food in refrigerators in Danish households in 2003 is 1,284 GWh. In order to determine the electricity use per kilo refrigerated food, data on the amount of food consumption by Danish households as well as the share of each food item that is stored in refrigerator are needed. Based on food balance sheets in FAOSTAT (2015), the total food and beverages consumption in Denmark is identified as 5.53 million tonne in 2003 (2.8 kg per capita per day). We have estimated that 60% of all food and beverages used by households is stored in refrigerator. By comparing the total electricity use for refrigerators (1,284 GWh) with the total use of food that is stored in refrigerators in Danish households in 2003 (3.32 million tonne), the electricity use per kg food can be calculated as 0.39 kWh/kg food.

Newer data suggest a lower share of household electricity use that goes to chilling and freezing: 18% in 2011 (Privat Boligen 2015), and according to Energistyrelsen (2015), it even lower at 14% for an unspecified year. However, it should be noted that there are no documentation of the data in these two data sources, and further Privat Boligen (2015), suggest that the total electricity use by Danish households in 2011 is 8,649 GWh – this is considerably lower than 10,111 GWh in 2010 which is the number that is reported by official energy statistics (Energistyrelsen 2014a).

EU27: For comparison, a similar calculation as the one for Denmark above is made for EU27. According to Bertoldi et al. (2012, p 40), 14.5% of the electricity use in European households in 2005 was used for refrigerators. In 2005, the total electricity use in European households was 804,900 GWh (Bertoldi et al. 2012, p 18). Hence, the electricity use for storage of food in refrigerators in European households in 2005 is 116,700 GWh. In order to determine the electricity use per kilo refrigerated food, data on the amount of food consumption by EU27 households as well as the share of each food item that is stored in refrigerator are needed. Based on food balance sheets in FAOSTAT (2015), the total food and beverages consumption in EU27 is identified as 486 million tonne in 2003 (2.7 kg per capita per day). It has been estimated that 60% of all food and beverages used by households is stored in refrigerator. By comparing the total electricity use for refrigerators (116,700 GWh) with the total use of food that is stored in refrigerators in European households in 2003 (292 million tonne), the electricity use per kg food can be calculated as 0.40 kWh/kg food.

It appears from the calculations for DK and EU27 that the specific electricity use for refrigeration per kg average food and drink are very close.

6.4.4 Electricity for dishwashing

Denmark: According to Gram-Hanssen (2005, p 19), 4% of the electricity use in Danish households in 2000 was used for dishwashing. Combining this with the total electricity use in Danish households (**section 6.4.1**) and the total food and drink consumption that generates the need for dishwashing (5.53 million tonne), the electricity use for dishwashing can be calculated as 0.074 kWh/kg food.

EU27: According to Bertoldi et al. (2012, p 56), the use of electricity for dishwashers in EU27 households was 25,900 GWh in 2005. Combining this with the total food and drink consumption that generates the need for dishwashing (486 million tonne), the electricity use for dishwashing can be calculated as 0.053 kWh/kg food.

One of the reasons why the electricity use is lower for the EU27 than for Denmark is probably that the market for dishwashers is not saturated in the EU27 (Bertoldi et al. 2012, p 56). This means that a larger share of dishes washed by hand can be expected in EU27 compared to Denmark. Since the water for dishwashing by hand needs to be heated, and since some of this is heated by electricity, it has been decided to use the electricity data for Denmark. These data are expected to be more representative for the total electricity use for dishwashing.

6.4.5 Water use for dishwashing

According to DANVA (2014), the use of water in the Danish households in 2013 was 38.9 m^3 per person. This corresponds to 219 million m^3. According to DANVA (2015), 10% of the water use in the households relates to dishwashing and cleaning, i.e. 21.9 million m^3 water relates to this. Combining this with the 5.53 million tonne food consumption (FAOSTAT 2015), the water use for dishwashing is estimated as 4.0 litre water per kg food.

6.4.6 Materials for treatment and methane from human digestion

Packaging waste: The amounts of packaging materials with Arla products to the households/end-use are assumed the same as the inputs of packaging materials to Arla. The latter is described in **section 5.4.** It is assumed that none of the packaging waste from dairy products is recycled or sent to composting or biogasification, i.e. all of the packaging waste is sent to landfill and waste incineration. According Eurostat (2015b), the proportions of municipal to landfill and incineration in the EU27 in 2013 was 54% and 46% respectively.

The amount of packaging waste per kg dairy product are shown in **Table 6.3**. The amounts have been calculated by dividing the amounts of packaging materials used by Arla Foods (**Table 5.5**) by the total amount of dairy products sold to end-users (7,680,000 tonne as of **Table 2.1**). It has been assumed that the amount of packaging used for by-products (see **Table 2.1**) is negligible.

TABLE 6.3: AMOUNT OF PACKAGING WASTE IN THE HOUSEHOLD/END-OF-LIFE STAGE IN 2014.

Packaging material for	Amount (tonne)	Amount per kg dairy product (kg/kg)
Plastics	101,000	0.0132
Paper	145,000	0.0189
Glass	23,000	0.0030
Metals	19,000	0.0025
Total	**288,000**	**0.038**

Food waste: Based on Weidema et al. (2008, p 116), the amount of dairy food inputs to households that are wasted, i.e. not ingested, is estimated as 20%. It should be noted that the impact of this estimate on the results of the current study is insignificant. This is because the functional unit is defined as the production of dairy products (and not ingested), and that the impacts from digesting and disposing off food are very small compared to the impacts from agriculture, dairy, retail and energy use in households. When disposing off food waste, this is done to landfill, incineration and composting. According to Eurostat (2015b), the proportions between these three waste management options in the EU27 in 2013 are 43%, 36% and 21% respectively.

Human digestion and excretion/urine to waste water treatment: The human excretion/urine to waste water treatment and methane emissions are included by means of the model developed by Muñoz et al. (2008). Other flows related to toilet visits, such as water use for toilet flush and hand wash, towels for hand drying and laundry of towels etc. are included by means of the generic household activity dataset for meals; 'EU27 140 Household use, meals' from the FORWAST database.

When using the model by Muñoz et al. (2008) for the calculation of human methane emissions and amounts of excretion/urine to waste water treatment, data on the amount of food intake as well as the composition of the food are needed. These data for dairy products are shown in **Table 6.4**.

TABLE 6.4: COMPOSITION OF ARLA DAIRY PRODUCTS IN GRAMS PER 100 G EDIBLE PORTION (THE 2% 'NON-MILK BASED PRODUCT' WERE NOT ACCOUNTED FOR IN THE AVERAGE COMPOSITION). FOOD COMPOSITION DATA ARE FROM (USDA 2015).

Impact category	Composition per 100g of edible portion				Average Arla dairy product
	Milk	**Cheese**	**Butter and spread**	**Powder**	**Weighted average (see Table 5.2)**
Water (g)	86	28	17	3.6	**70**
Protein (g)	3.7	36	0.85	36	**8.9**
Fat (g)	2.7	30	81	0.75	**8.1**
Carbohydrate (g)	6.8	0.90	0.060	52	**9.0**
Fiber (g)	0.095	0	0	0	**0.07**
Alcohol (g)	0	0	0	0	**0**
P (g)	0.11	0.68	0.024	0.98	**0.22**
Na (g)	0.064	0.76	0.44	0.54	**0.18**
K (g)	0.17	0.15	0.026	1.7	**0.27**
Ca (g)	0.14	1.0	0.024	1.2	**0.29**
Other	0.221	2.51	0.576	3.23	2.97
Total	**100**	**100**	**100**	**100**	**100**

Based on the data above, the amount of excretion/urine and methane emissions can be calculated as 0.070 kg dm and 0.16 g CH_4 per kg ww average dairy product ingested. When these data are related to the reference flow of the use stage LCA activity, it is taken into account that only 80% of the dairy product is ingested, while the remaining 20% is disposed of via the municipal waste management system. The latter is described in the section above.

6.4.7 Summary of the inventory of the household activity

TABLE 6.5: SUMMARY OF LIFE CYCLE INVENTORY OF THE HOUSEHOLD ACTIVITY. ONLY THE FLOWS, WHICH ARE CHANGED, COMPARED TO THE ORIGINAL FORWAST DATASET ('HOUSEHOLD USE, MEALS, EU27) ARE SHOWN HERE.

	Unit	Household activity	Applied LCI data
Output: Reference flow			
Household use, dairy products	kg WW	0.41	Reference flow changed from 1 EUR2003 to 0.41 kg input of food & beverage to households.
Inputs			
Electricity	kWh	0.19	Electricity for refrigerator and dishwashing. Electricity LCI data, see **section 4.4.**
Water	litre	1.64	See **section 4.2.13**.
Output: Materials for treatment			
Excretion/urine to waste water treatment	kg DM	0.023	EU27 114 Waste treatment, Waste water treatment, food (**section 4.1**)
Food waste to incineration	kg DM	0.0087	See **Table 4.7**
Food waste to landfill	kg DM	0.010	
Food waste to composting	kg DM	0.0051	
Plastics waste to incineration	kg DM	0.0060	
Plastics waste to landfill	kg DM	0.0071	
Paper waste to incineration	kg DM	0.0087	
Paper waste to landfill	kg DM	0.010	
Glass waste to incineration	kg DM	0.0014	
Glass waste to landfill	kg DM	0.0016	
Metal waste to incineration	kg DM	0.0011	
Steel waste to landfill	kg DM	0.0011	
Aluminium waste to landfill	kg DM	0.00021	
Output: Emissions from digestion			
Methane	kg	0.000052	Emission to air
Eliminated original inputs			

The original dataset for 'Household use, meals, EU27' includes a number of inputs/outputs that are included in other parts of the LCI. To avoid double counting, these flows are deleted here. This involves:

- Inputs of food products are deleted (included in **section 5**)
- Inputs of retail services (included in **section 6.2**)
- Inputs of fuels, vehicles for transport and related services are deleted (included in **section 6.3**). Also, the emissions relating to the combustion of transport fuels are deleted.
- Emissions related to the combustion of fuels heating (for food preparation) are deleted (this does not relate to dairy products).

7. Life cycle impact assessment at mid-point

In this chapter, the life cycle impact assessment at mid-point of the impact pathway is presented, i.e. the individual impacts are evaluated in their different physical units. The monetarisation of impacts is presented in **chapter 8**. As described in **section 3.1**, the results are calculated using two different modelling approaches, i.e. the consequential approach (cause-effect based) and the attributional approach (normative/rule based). The mid-point results for both approaches are shown in **Table 7.1**. The results refer to the functional unit defined in **section 2.3**: "*Arla Foods' entire production in 2014, including upstream and downstream activities*".

TABLE 7.1: LIFE CYCLE IMPACT ASSESSMENT (LCIA) RESULTS: MID-POINT EVALUATION. RESULTS ARE SHOWN FOR TWO MODELLING ASSUMPTIONS IN THE LIFE CYCLE INVENTORY: CONSEQUENTIAL (CAUSE-EFFECT BASED) AND ATTRIBUTIONAL (NORMATIVE/RULE BASED).

		Indicator results	
Impact category	**Unit**	**Consequential**	**Attributional**
Stepwise. These impacts are monetarised in chapter 8			
Global warming	million tonne CO_2-eq	20.2	26.6
Respiratory inorganics	tonne $PM_{2.5}$-eq	23,551	19,018
Respiratory organics	million pers*ppm*h	14	22
Nature occupation	PDF*ha*year	544,000	-26,000
Acidification	ha UES	385,000	287,000
Eutrophication, terrestrial	ha UES	1,626,000	1,139,000
Eutrophication, aquatic	tonne NO_3-eq	540,000	376,000
Photochemical ozone, vegetat.	million ha*ppm*hours	14	21
Human toxicity, carcinogens	tonne C_2H_3Cl-eq	232,000	144,000
Human toxicity, non-carc.	tonne C_2H_3Cl-eq	129,000	94,000
Ecotoxicity, aquatic	million tonne TEG-eq w	492	404
Ecotoxicity, terrestrial	million tonne TEG-eq s	63	50
Ionizing radiation	million Bq C-14-eq	54,000	188,000
Non-renewable energy	TJ primary	136,000	164,000
Mineral extraction	TJ extra	740	618
Additional impacts. These impacts are not monetarised			
Land occupation	million ha	-3.63	2.74
Water use, blue water footprint	million m^3	194	293

7.1 Identification of the most significant impacts

In order to focus the further evaluation of the mid-point results, the most significant/important impact categories are identified. In order to do so, three different weighting methods are used: Stepwise (Weidema 2009) (**Figure 7.1**), ReCiPe (Goedkoop et al. 2013) (**Figure 7.2**) and Impact 2002+ (Jolliet et al. 2003) (**Figure 7.3**). Updated versions of all three methods are available for SimaPro 8. The weighting in Stepwise is the same as used for the monetarisation of impacts, which is presented in **chapter 8**. All three methods are damage-oriented methods, where the midpoints' contributions are quantified to a limited number of damage categories. For ReCiPe, the damage categories are human health, ecosystems and resources. Impact 2002+ uses the same three damage categories but keeps climate change separate from these. Impacts on human health is measured in disability adjusted life years (DALY), impacts on ecosystems are measured in potential disappeared fraction x area x time (PDF*ha*year), the impact on resources is measured in monetary units, and climate change is measured in kg CO_2-equivalents. When aggregating the three ReCiPe damage categories, human health and ecosystems are weighted equally while resources are given the half weight relative to one of the other damage categories. The weighting in Impact 2002+ give equal weight to the four damage categories human health, ecosystems, resources and climate change. In the Stepwise method, the same damage categories as in ReCiPe are used, with equivalent measurement units (QALY = DALY and BAHY = 10,000 PDF*ha*year), but the weighting is done with a conversion factor of 53 BAHY/QALY and 1400 EUR/BAHY, based on a monetary valuation of the three damage categories. This is the same weighting method, which is used for calculating the monetarised results with the Stepwise method (see section 3.5).

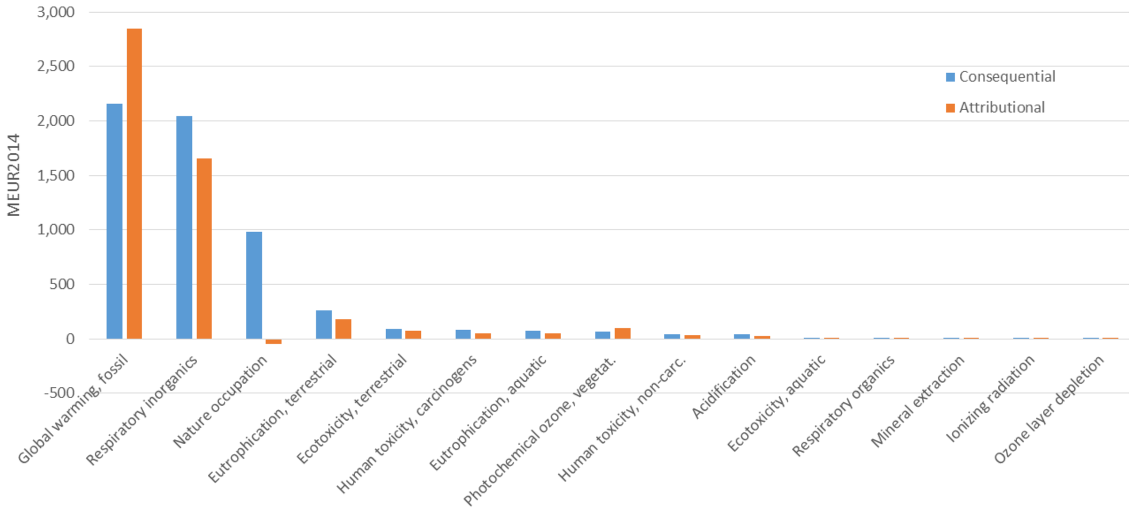

FIGURE 7.1: IDENTIFICATION OF THE MOST IMPORTANT IMPACT CATEGORIES USING THE **STEPWISE** METHOD (WEIDEMA 2009). RESULTS ARE SHOWN FOR CONSEQUENTIAL AND ATTRIBUTIONAL MODELLING APPROACH IN LCI.

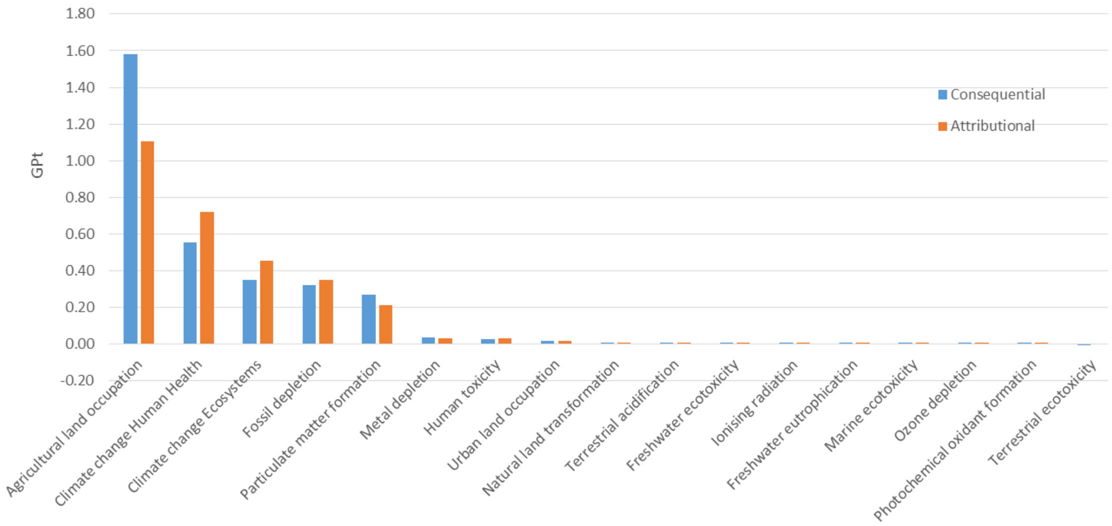

FIGURE 7.2: IDENTIFICATION OF THE MOST IMPORTANT IMPACT CATEGORIES USING THE **RECIPE** ENDPOINT (H/A) V1.11 METHOD (GOEDKOOP ET AL. 2009). RESULTS ARE SHOWN FOR CONSEQUENTIAL AND ATTRIBUTIONAL MODELLING APPROACH IN LCI.

For the result calculated with the ReCiPe method, it should be noted that the exchange 'occupation of grassland' is not included in the method. 'Occupation, grassland' is used by beef production in Brazil (which is substituted in the Consequential calculations). This means that the consequential result for agricultural land occupation in **Figure 7.2** appears as positive, but it should have been negative.

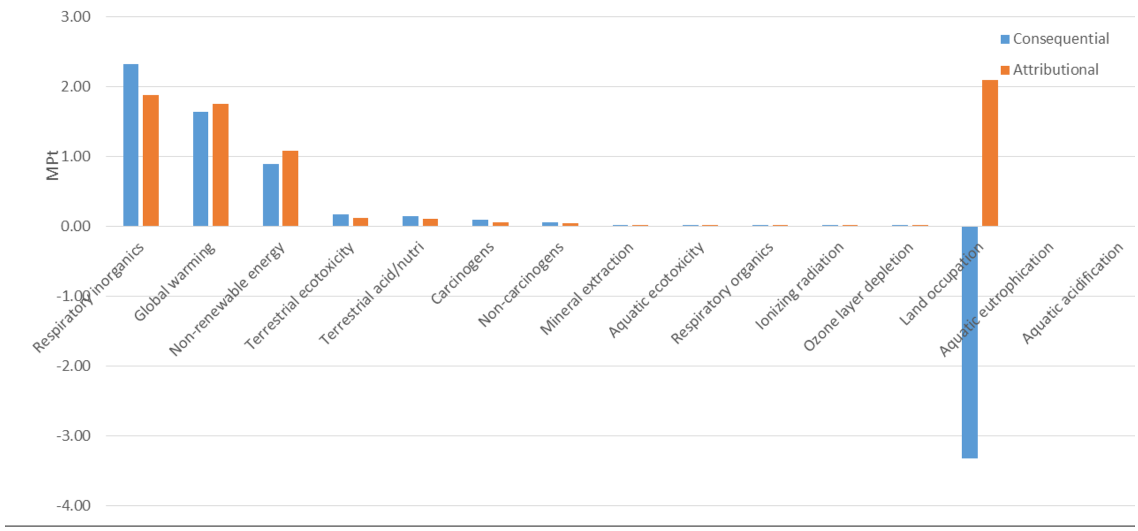

FIGURE 7.3: IDENTIFICATION OF THE MOST IMPORTANT IMPACT CATEGORIES USING THE **IMPACT 2002+** V2.12 METHOD (JOLLIET ET AL. 2003). RESULTS ARE SHOWN FOR CONSEQUENTIAL AND ATTRIBUTIONAL MODELLING APPROACH IN LCI.

From **Figure 7.1**, **Figure 7.2** and **Figure 7.3** it appears that the three weighting methods agree that the following impacts are among the most important:

- Global warming
- Respiratory inorganics / particulate matter formation
- Nature occupation / land occupation (Impact 2002+ show negative result for the consequential result, but this is because the occupation of pasture is given the same weight as occupation of arable land. Furthermore, ReCiPe does not include characterisation factors for 'grassland', which is used in Brazil).

Besides the three impacts above, the ReCiPe and the Impact 2002+ methods point to fossil depletion / non-renewable energy as important impacts, while the Stepwise method does not give very high value to these impacts (or to resource extraction in general). The main reason for this difference is that ReCiPe and Impact 2002+ regard the resource uses as unsustainable.

In the following detailed evaluation of impacts, it has been chosen to focus on global warming, respiratory inorganics, nature occupation and non-renewable energy.

7.2 Detailed mid-point results, consequential modelling

In this section, the contributions to global warming, respiratory inorganics, nature occupation and non-renewable energy for the consequential approach are described in detail. **Table 7.2**, **Table 7.3**, **Figure 7.4** and **Figure 7.5** provide an overview of the contribution to these four impact categories, and in the subsequent sections, the contribution to global warming, respiratory inorganics and nature occupation are further analysed.

Table 7.2 and **Figure 7.4** show the results divided into different life cycle stages. The table is divided into four stages for upstream/direct impacts and two downstream. The upstream/direct stages are: 1) Milk production (at farm gate), 2) Other raw materials (vegetable oils, fruit juice, sugar etc.), 3) Packaging, and 4) 'Dairy sites & offices'. The latter includes everything of the upstream and direct impacts that is not covered by the first four categories. The two downstream life cycle stages are transport of dairy products from Arla sites to retail, and 'retail, consumer & waste'.

Table 7.3 and **Figure 7.5** show the results divided into different countries. The specified locations do not exactly match with the locations where the emissions are actually taking place. This has not been possible because of lack of information on where the all activities in the product system are located, e.g. when diesel is used in Denmark, it is not known where the diesel has been produced. Instead, the specified locations are based on where the production sites are located (for upstream and direct impacts) and the destination of where the dairy products are used (for downstream).

TABLE 7.2: LIFE CYCLE IMPACT ASSESSMENT (LCIA) RESULTS DIVIDED ON LIFE CYCLE STAGES FOR SELECTED IMPACT CATEGORIES. **CONSEQUENTIAL MODELLING**.

Life cycle stages	Global warming million t CO2-eq.	Respiratory inorganics tonne PM2.5 eq.	Nature occupation PDF*ha*year	Non-renewable energy TJ primary
Milk production	12.0	17,134	429,560	53,778
Other raw materials	0.73	581	17,045	2,964
Packaging	0.89	497	34,776	12,779
Dairy sites & offices	1.38	867	30,759	14,870
Transports	0.52	731	213	8,467
Retail, consumer & waste	4.69	3,790	31,647	44,142
Total	**20.2**	**23,600**	**544,000**	**137,000**

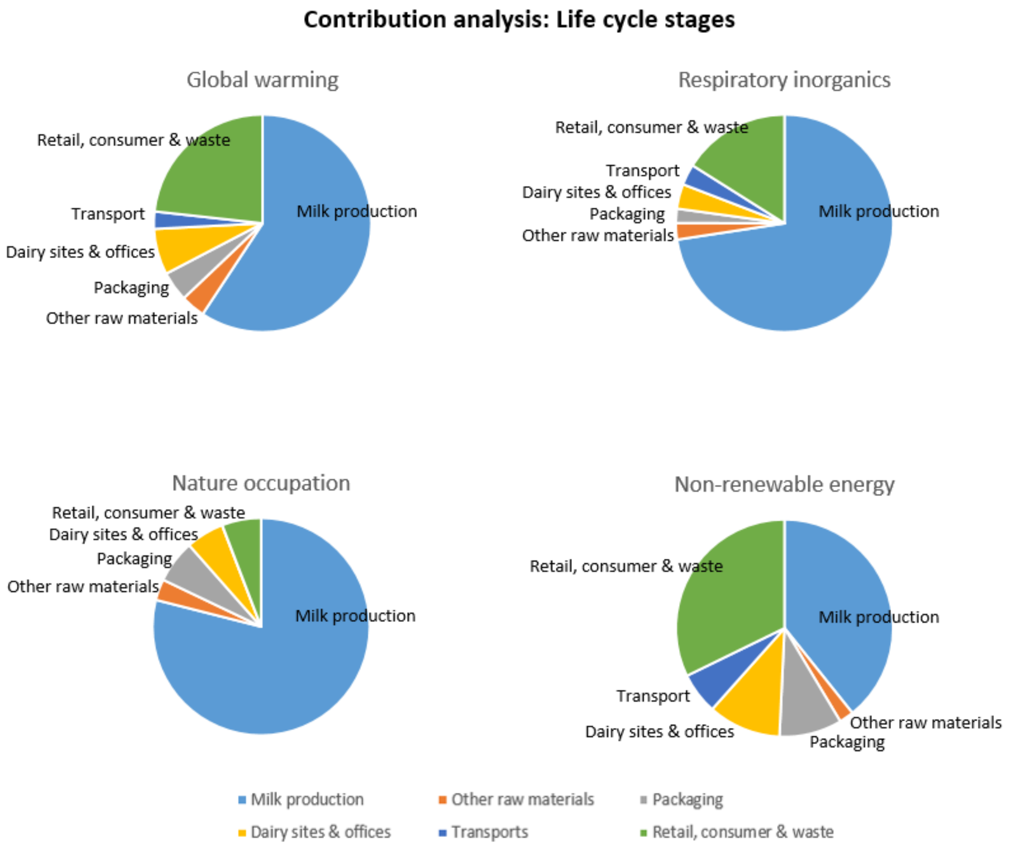

FIGURE 7.4: CONTRIBUTION ANALYSIS: BREAKING THE RESULTS DOWN INTO LIFE CYCLE STAGES. **CONSEQUENTIAL MODELLING**.

TABLE 7.3: LIFE CYCLE IMPACT ASSESSMENT (LCIA) RESULTS DIVIDED ON COUNTRIES FOR SELECTED IMPACT CATEGORIES. **CONSEQUENTIAL MODELLING**.

Countries	**Global warming** million t CO2-eq.	**Respiratory inorganics** tonne PM2.5 eq.	**Nature occupation** PDF*ha*year	**Non-renewable energy** TJ primary
Germany (DE)	3.59	4,650	107,500	24,300
Denmark (DK)	5.53	7,310	177,800	34,000
Sweden (SE)	2.86	2,930	69,100	17,800
United Kingdom (UK)	6.04	6,550	115,100	43,100
Finland (FI)	0.40	400	5,900	3,500
The Netherlands (NL)	0.51	510	15,500	3,600
Rest of Europe	0.21	180	30	2,100
Rest of World	1.05	1,030	52,900	8,100
Total	**20.2**	**23,600**	**544,000**	**137,000**

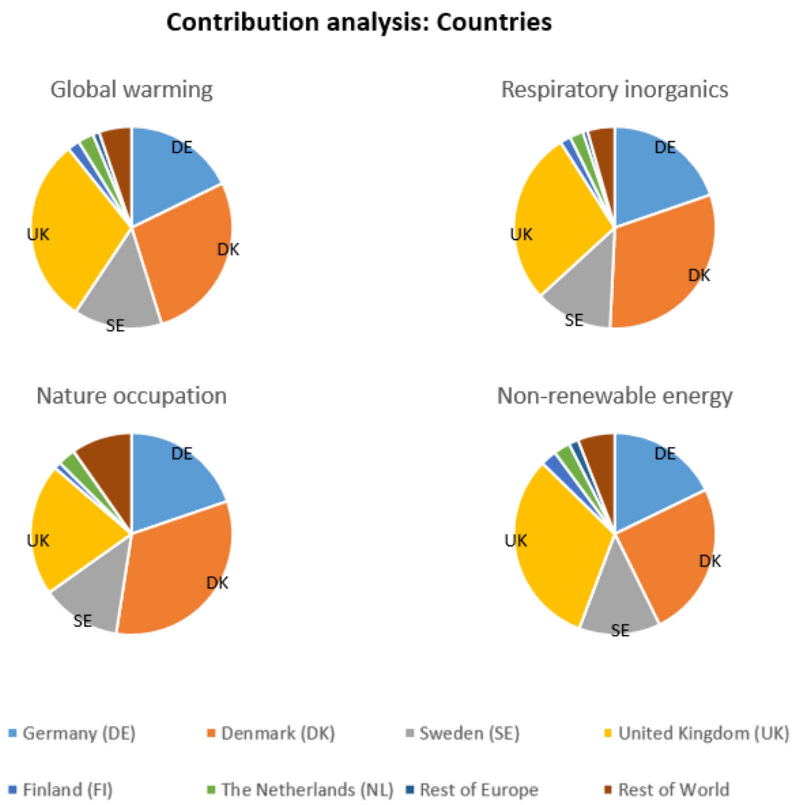

FIGURE 7.5: CONTRIBUTION ANALYSIS: BREAKING THE RESULTS DOWN INTO COUNTRIES BASED ON LOCATION OF SITES AND END-USE. **CONSEQUENTIAL MODELLING**.

7.2.1 Global warming

This section analyses the contribution to global warming in detail. The total contribution to global warming is 20.2 million tonne CO_2-eq (GWP_{100}). This figure is broken down into its main contributors in **Table 7.4**.

TABLE 7.4: CONTRIBUTION ANALYSIS **FOR GHG EMISSIONS. CONSEQUENTIAL MODELLING.**

Life cycle stage	GHG emissions (million tonne CO_2-eq)		
Upstream and Arla emissions			
Raw materials, energy and waste			
Raw milk	12.0		
Packaging	0.89		
Fuels incl. combustion	0.53		
Butter, cheese, powder, whey	0.36		
Vegetable oils	0.25		
Other	0.21		
Electricity and heat	0.13		
Sugar and fruit/jam	0.12		
Waste water treatment	0.11		
Waste treatment	-0.053	**14.5**	
Capital goods and services			
Capex/MRO	0.22		
Operating services	0.094		
Marketing	0.045		
Professional service	0.036		
No priority	0.031		
Logistics	0.011		
Heavy equipment	0.0090	**0.45**	
Transport			
Transport, internal, lorry (diesel)	0.19		
Transport, internal, lorry (RME)	0.0092		
Transport, external, air	0.0052		
Transport, external, lorry	0.20		
Transport, external, ship	0.043		
Transport, external, train	0.00029	**0.44**	**15.4**
Downstream			
Distribution from Arla to retail		**0.074**	
Retail sale		**0.54**	
Transport from retail to end user		**1.46**	
End-user consumption		**2.68**	**4.76**
Total			**20.2**

It appears from **Table 7.4** that the upstream and direct emissions of Arla Foods account for 76% of the GHG emissions. The input of raw milk alone accounts for 59% of the total GHG emissions. Other significant inputs are packaging (4%), fuels incl. combustion (3%), transport (2%) and the production of purchased dairy products (2%). Arla Foods' use of capital goods and services account for 2%.

The downstream contribution account for 24% of the total GHG emissions. Hereof the largest contributor is the end-user consumption, which accounts for 13% of the total GHG emissions. Here, the most significant contributions relate to electricity for refrigerator and dishwashing and to landfill of food waste. The transport from retail to end user is also significant; it contributes with 7% of the total GHG emissions. The retail account for 3%. The main contributor in retail is electricity use (incl. electricity for cooling).

The consequential version of the results includes indirect land use changes (iLUC). This alone contributes with 5.38 million tonne CO_2-eq. This is composed of induced impacts from the feed for the milk production at 6.27 million tonne CO_2-eq. and avoided impacts related to the substituted beef (milk is produced with beef as a by-product) at -0.89 million tonne CO_2-eq.

The following emissions are the most important contributors to the overall impact on global warming: carbon dioxide (68%), methane (23%), nitrous oxide (10%), and other emissions (<1%). The major sources of CO_2 are indirect land use changes (24%) and burning of diesel in agricultural machinery (6%) and many small contributions relating to electricity, transport and materials. Methane emissions almost exclusively occur in the animal activities where the majority is related to enteric fermentation, while a smaller part is related to manure management. Nitrous oxide mainly occurs as a result of application of mineral fertiliser and manure of agricultural soils. 65% hereof is related to indirect land use changes (intensification of cropland).

7.2.2 Respiratory inorganics

This section analyses the contribution to respiratory inorganics in detail. The total contribution to respiratory inorganics is 26 thousand tonne $PM_{2.5}$-eq. This figure is broken down in **Table 7.5**.

TABLE 7.5: CONTRIBUTION ANALYSIS FOR **RESPIRATORY INORGANICS. CONSEQUENTIAL MODELLING**.

Life cycle stage	Respiratory inorganics (tonne $PM_{2.5}$-eq)		
Upstream and Arla emissions			
Raw materials, energy and waste			
Raw milk	17,134		
Packaging	497		
Butter, cheese, powder, whey	347		
Electricity and heat	190		
Other	158		
Vegetable oils	157		
Fuels incl. combustion	117		
Sugar and fruit/jam	77		
Waste treatment	23		
Waste water treatment	11	**18,710**	
Capital goods and services			
Capex/MRO	159		
Operating services	67		
Marketing	32		
Professional service	26		
No priority	22		
Logistics	14		
Heavy equipment	6.7	**326**	
Transport			
Transport, internal, lorry (diesel)	229		
Transport, internal, lorry (RME)	19		
Transport, external, air	4.0		
Transport, external, lorry	251		
Transport, external, ship	138		
Transport, external, train	0.4	**641**	**19,678**
Downstream			
Distribution from Arla to retail		**90**	
Retail sale		**385**	
Transport from retail to end user		**1,037**	
End-user consumption		**2,368**	**3,880**
Total			**23,558**

The contributing activities to respiratory inorganics are similar as the ones of global warming (**section 7.2.1**). It appears from **Table 7.5** that the upstream and direct emissions of Arla Foods account for 84% of the impact on respiratory inorganics. The input of raw milk alone accounts for 73% of the impact. Other significant inputs are transport (3%) and packaging (2%). Arla Foods' use of capital goods and services account for 1%.

The downstream contribution account for 16% of the total contribution to respiratory inorganics. Hereof the largest contributors are the end-user consumption (10%) and the transport from retail to end user (4%). Of the end use consumption, the most significant contributions relate to electricity for refrigerator and dishwashing and to waste treatment. The retail account for 2%. The main contributor in retail is electricity use (incl. electricity for cooling).

Indirect land use changes (iLUC) are induced by land using activities, mainly for cultivation of cattle feed. iLUC alone contributes with 17% of the total contribution to respiratory inorganics.

The following emissions are the most important contributors to the overall impact on respiratory inorganics: ammonia (55%), nitrogen oxides (23%), particulates (16%), and sulphur dioxide (7%) and other emissions (<1%). The major sources of ammonia are field emissions from crop cultivation (26%), indirect land use changes (24%), emissions from animal excretion (excluding land application) (22%) and manure land application (9%). Nitrogen oxide emissions originate from combustion of diesel in agricultural machinery (27%), field emissions (20%) and transport (19%).

7.2.3 Nature occupation

This section analyses the contribution to nature occupation in detail. The contribution to nature occupation almost exclusively relates to the production of raw milk, where crops and grass occupy land. A smaller use of land is related to forestry for packing paper. It should be noted that the nature occupation impacts occurs via the iLUC model. This is because, occupying a piece of land in Europe, with e.g. barley, will not have any impacts in Denmark since the marginal use of arable land is agriculture anyway. A change in demand for arable land in Denmark will instead lead to accelerated transformation from secondary forest to arable land somewhere else. The accelerated denaturalisation takes place in regions with tropical rainforest where arable land expansion mainly takes place.

In **Figure 7.6** below, the direct land occupation by crops and grass (causing the indirect land use changes) are shown. The total land occupation is -3.63 million ha*years. This involves 3.30 ha*year occupation of arable land in DE, DK, SE, UK (and other countries), and -6.93 million ha*year grassland in BR. Whenever the location of the land occupation is not known, this is specified with 'unknown' in the figure. The occupation of arable land relates to the milk system and associated cultivation of feed, whereas the negative grassland in Brazil relates to the substituted beef from milk production. The reason why the net land use becomes negative is that the substituted beef system in Brazil is very extensive, i.e. the animal density on the affected grasslands is very low. It should also be noted that the total impact on nature occupation (biodiversity) is not negative. This is because the substituted occupation of grassland does not have as high an impact on nature occupation as occupation of arable land.

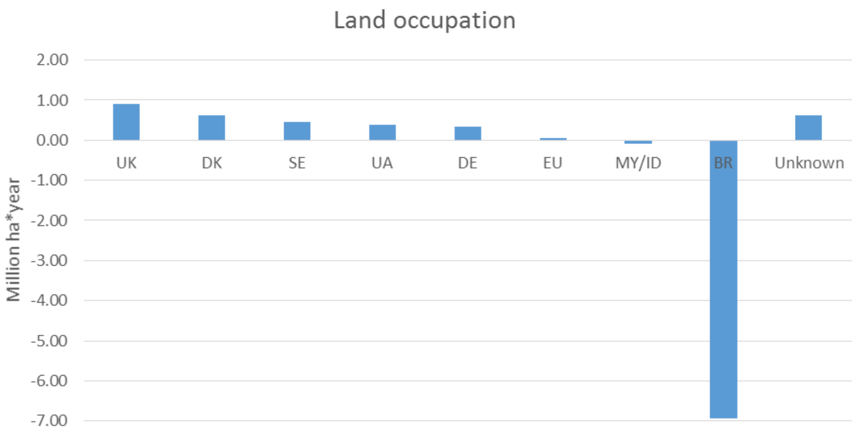

FIGURE 7.6: LAND OCCUPATION BY COUNTRY (CONSEQUENTIAL).

7.3 Detailed mid-point results, attributional modelling

In this section the contributions to global warming, respiratory inorganics, nature occupation and non-renewable energy for the attributional approach are described in detail. **Table 7.6**, **Table 7.6**, **Figure 7.7** and **Figure 7.8** provide an overview of the contribution to these four impact categories, and in the subsequent sections, the contribution to global warming, respiratory inorganics and nature occupation are further analysed.

Table 7.6 and **Figure 7.7** show the results divided into different life cycle stages. The table is divided into four stages for upstream/direct impacts and two downstream. The upstream/direct stages are: 1) Milk production (at farm gate), 2) Other raw materials (vegetable oils, fruit juice, sugar etc.), 3) Packaging, and 4) 'Dairy sites & offices'. The latter includes everything of the upstream and direct impacts that is not covered by the first four categories. The two downstream life cycle stages are transport of dairy products from Arla sites to retail, and 'retail, consumer & waste'.

Table 7.7 and Figure 7.8 show the results divided into different countries. The specified locations do not exactly match with the locations where the emissions are actually taking place. This has not been possible because of lack of information on where the all activities in the product system are located, e.g. when diesel is used in Denmark, it is not known where the diesel has been produced. Instead, the specified locations are based on where the production sites are located (for upstream and direct impacts) and the destination of where the dairy products are used (for downstream).

TABLE 7.6: LIFE CYCLE IMPACT ASSESSMENT (LCIA) RESULTS DIVIDED ON LIFE CYCLE STAGES FOR SELECTED IMPACT CATEGORIES. **ATTRIBUTIONAL MODELLING**.

Life cycle stages	Global warming million t CO2-eq.	Respiratory inorganics tonne PM2.5 eq.	Nature occupation PDF*ha*year	Non-renewable energy TJ primary
Milk production	16.6	12,137	-19,974	53,911
Other raw materials	2.33	1,559	-241	3,434
Packaging	0.69	408	-163	14,373
Dairy sites & offices	1.42	796	-2,446	25,245
Transports	0.51	736	-512	8,422
Retail, consumer & waste	5.10	3,365	-2,665	58,615
Total	**26.6**	**19,000**	**-26,000**	**164,000**

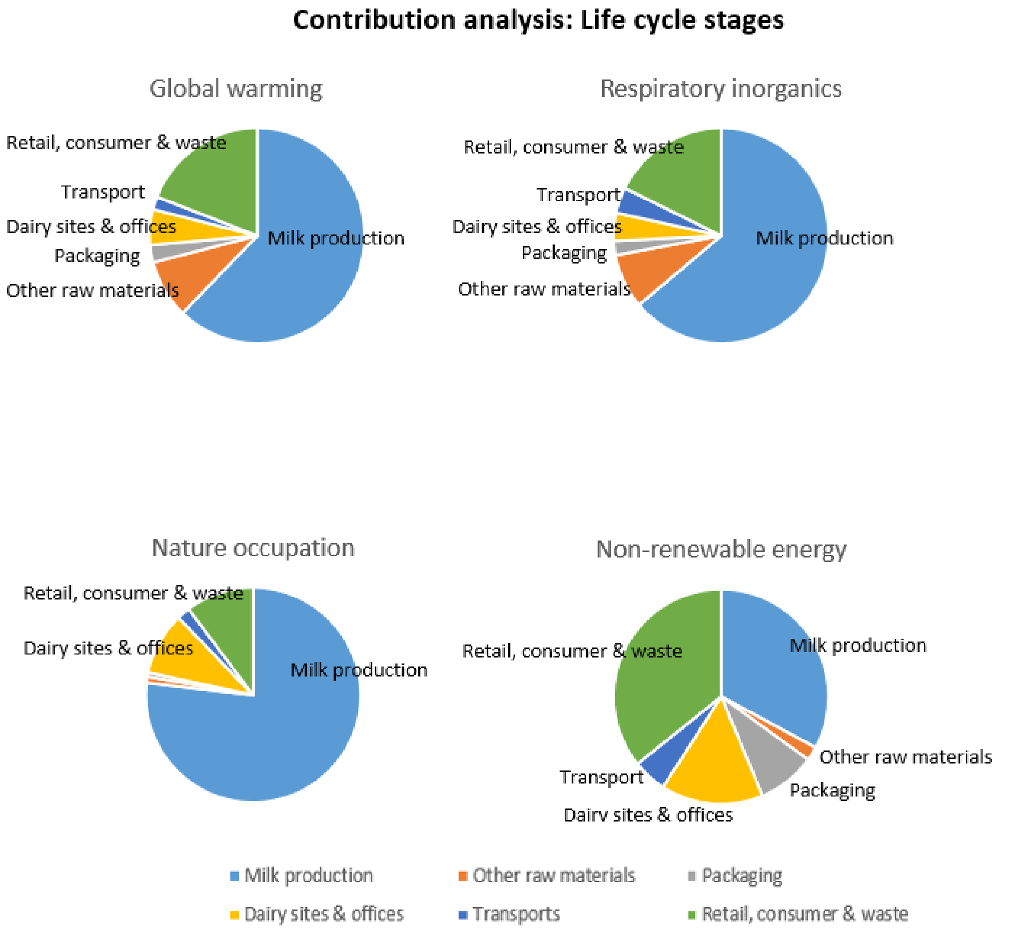

FIGURE 7.7: CONTRIBUTION ANALYSIS: BREAKING THE RESULTS DOWN INTO LIFE CYCLE STAGES. **ATTRIBUTIONAL MODELLING**.

TABLE 7.7: LIFE CYCLE IMPACT ASSESSMENT (LCIA) RESULTS DIVIDED ON COUNTRIES FOR SELECTED IMPACT CATEGORIES. **ATTRIBUTIONAL MODELLING**.

Countries	**Global warming** million t CO2-eq.	**Respiratory inorganics** tonne PM2.5 eq.	**Nature occupation** PDF*ha*year	**Non-renewable energy** TJ primary
Germany (DE)	5.30	3,650	-4,800	32,200
Denmark (DK)	7.77	5,660	-3,700	38,600
Sweden (SE)	3.20	2,350	-11,100	18,000
United Kingdom (UK)	7.20	5,150	-400	49,600
Finland (FI)	0.46	330	-300	4,100
The Netherlands (NL)	0.59	400	-600	4,400
Rest of Europe	0.23	160	0	2,700
Rest of World	1.90	1,330	-5,500	14,800
Total	**26.6**	**19,000**	**-26,000**	**164,000**

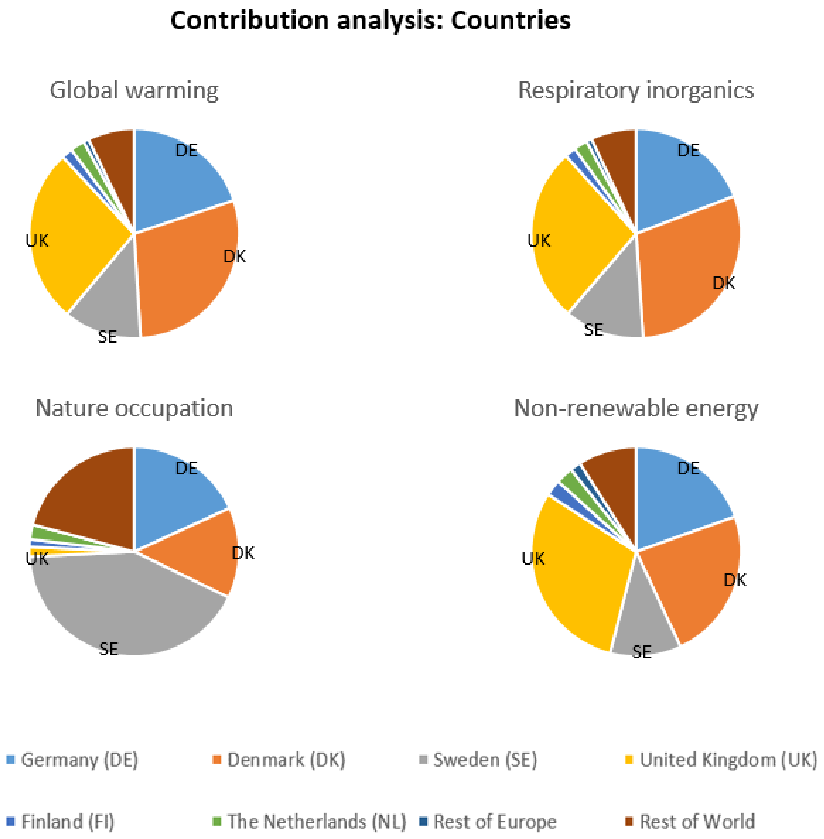

FIGURE 7.8: CONTRIBUTION ANALYSIS: BREAKING THE RESULTS DOWN INTO COUNTRIES BASED ON LOCATION OF SITES AND END-USE. **ATTRIBUTIONAL MODELLING**.

7.3.1 Global warming

This section analyses the contribution to global warming in detail. The total contribution to global warming is 26.6 million tonne CO_2-eq. This figure is broken down into contributions in **Table 7.8**.

TABLE 7.8: CONTRIBUTION ANALYSIS FOR **GHG EMISSIONS. ATTRIBUTIONAL** MODELLING.

Life cycle stage	GHG emissions (million tonne CO_2-eq)		
Upstream and Arla emissions			
Raw materials, energy and waste			
Raw milk	16.6		
Butter, cheese, powder, whey	2.04		
Packaging	0.69		
Fuels incl. combustion	0.48		
Electricity and heat	0.43		
Other	0.21		
Vegetable oils	0.18		
Waste water treatment	0.12		
Sugar and fruit/jam	0.11		
Waste treatment	-0.30	**20.6**	
Capital goods and services			
Capex/MRO	0.24		
Operating services	0.093		
Marketing	0.046		
Professional service	0.039		
No priority	0.033		
Logistics	0.011		
Heavy equipment	0.0101	**0.47**	
Transport			
Transport, internal, lorry (diesel)	0.19		
Transport, internal, lorry (RME)	0.0076		
Transport, external, air	0.0051		
Transport, external, lorry	0.20		
Transport, external, ship	0.045		
Transport, external, train	0.00036	**0.44**	**21.5**
Downstream			
Distribution from Arla to retail		**0.073**	
Retail sale		**0.73**	
Transport from retail to end user		**1.04**	
End-user consumption		**3.32**	**5.17**
Total			**26.6**

It appears from **Table 7.8** that the upstream and direct emissions of Arla Foods account for 81% of the GHG emissions. The input of raw milk alone accounts for 62% of the total GHG emissions. Other significant inputs are the production of purchased dairy products (8%), packaging (3%), fuels incl. combustion (2%) and transport (2%). Arla Foods' use of capital goods and services account for 2%.

The downstream contribution accounts for 19% of the total GHG emissions. Hereof the largest contributor is the end-user consumption, which accounts for 12% of the total GHG emissions. Here, the most significant contributions relate to electricity for refrigerator and dishwashing and to landfill of food waste. The transport from retail to end user is also significant; it contributes with 4% of the total GHG emissions. The retail account for 3%. The main contributor in retail is electricity use (incl. electricity for cooling).

The attributional results do not include emissions from indirect land use changes. The International Dairy Federation Guideline on life cycle assessment (IDF 2010) however mentions an approach to account for land use change emissions. When applying this approach, an additional 7.16 million tonne CO_2-eq. must be added to the total result of 26.6 million tonne CO_2-eq. in **Table 7.8**. It should be noted that the IDF approach is based on the historical land cover on the fields where the crops for animal feed are grown – and therefore is not related to the actual effects of using land – and therefore, it is not recommended to use this method. The method prescribes that if crops are grown in a country where deforestation is taking place, i.e. soybean in Brazil or oil palm in Malaysia or Indonesia for the current study, then the total CO_2 emissions from the change in carbon stock are included, and then this is divided by 20 year to allocate the emissions over a given timeframe.

The following emissions are the most important contributors to the overall impact on global warming: carbon dioxide (45%), methane (43%), nitrous oxide (14%), and other emissions (<1%). The major sources of CO_2 are electricity (25%) and burning of diesel in agricultural machinery (5%) and many small contributions relating to electricity, transport and materials. Methane emissions almost exclusively occur in the animal activities where the majority is related to enteric fermentation, while a smaller part is related to manure management. Nitrous oxide mainly occurs as a result of application of mineral fertiliser and manure of agricultural soils.

7.3.2 Respiratory inorganics

This section analyses the contribution to respiratory inorganics in detail. The total contribution to respiratory inorganics is 19,000 tonne $PM_{2.5}$-eq. This figure is broken down in **Table 7.9**.

TABLE 7.9: CONTRIBUTION ANALYSIS FOR **RESPIRATORY INORGANICS. ATTRIBUTIONAL** MODELLING.

Life cycle stage	Respiratory inorganics (tonne $PM_{2.5}$-eq)		
Upstream and Arla emissions			
Raw materials, energy and waste			
Raw milk	12,137		
Butter, cheese, powder, whey	1,334		
Packaging	408		
Electricity and heat	210		
Vegetable oils	154		
Other	143		
Fuels incl. combustion	99		
Sugar and fruit/jam	70		
Waste treatment	36		
Waste water treatment	11	**14,600**	
Capital goods and services			
Capex/MRO	161		
Operating services	60		
Marketing	29		
Professional service	24		
No priority	21		
Logistics	14		
Heavy equipment	6.8	**315**	
Transport			
Transport, internal, lorry (diesel)	231		
Transport, internal, lorry (RME)	18		
Transport, external, air	4.0		
Transport, external, lorry	252		
Transport, external, ship	140		
Transport, external, train	0.4	**645**	**15,561**
Downstream			
Distribution from Arla to retail		**91**	
Retail sale		**360**	
Transport from retail to end user		**664**	
End-user consumption		**2,342**	**3,456**
Total			**19,017**

The contributing activities to respiratory inorganics are similar as the ones for global warming (**section 7.3.1**). It appears from **Table 7.9** that the upstream and direct emissions of Arla Foods account for 82% of the impact on respiratory inorganics. The input of raw milk alone accounts for 64% of the impact. Other significant inputs are the production of purchased dairy products (7%), transport (3%) and packaging (2%). Arla Foods' use of capital goods and services account for 2%.

The downstream contribution accounts for 18% of the total contribution to respiratory inorganics. Hereof the largest contributors are the end-user consumption (12%) and the transport from retail to end user (3%). Of the end use consumption, the most significant contributions relate to electricity for refrigerator and dishwashing and to waste treatment. The retail accounts for 2%. The main contributor in retail is electricity use (incl. electricity for cooling).

The following emissions are the most important contributors to the overall impact of respiratory inorganics: ammonia (46%), nitrogen oxides (29%), particles (17%), sulphur dioxide (9%), and other emissions (<1%). The major sources of ammonia are field emissions from crop cultivation (55%), emissions from animal excretion (excluding land application) (26%). Nitrogen oxide emissions originate from combustion of diesel in agricultural machinery (20%), field emissions (27%) and transport (10%).

7.3.3 Nature occupation

The contribution to nature occupation almost exclusively relates to the production of raw milk, where crops and grass occupy land. A smaller use of land is related to forestry for packing paper. For the results calculated using the consequential approach, the nature occupation impacts occurs via the iLUC model, while here for the attributional results, indirect land use changes are not included - only direct land use changes are included. The overall impact on nature occupation is negative. This is because extensive pastures in DE, DE, SE and UK are used in the production system. Since these lands host more biodiversity than the marginal arable land, the impact becomes negative.

In **Figure 7.9** below, the direct land occupation by crops and grass (causing the indirect land use changes) are shown. The total land occupation is 2.74 million ha*years. Whenever the location of the land occupation is not known, this is specified with 'unknown' in the figure.

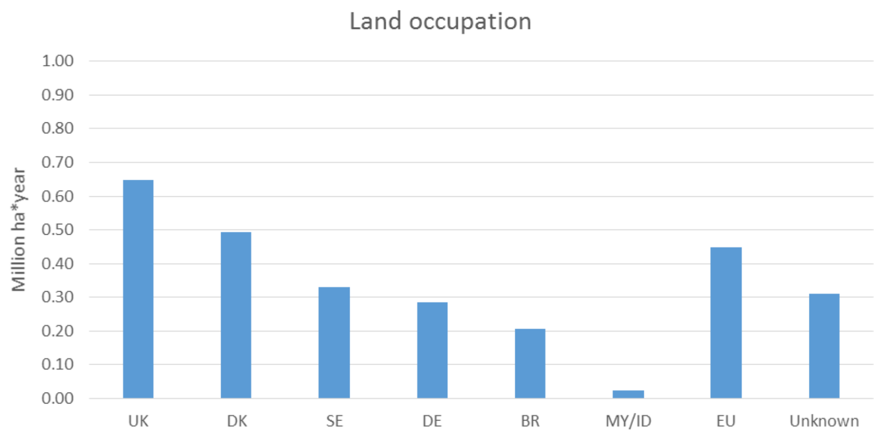

FIGURE 7.9: LAND OCCUPATION BY COUNTRY (ATTRIBUTIONAL).

8. Life cycle impact assessment – end-point evaluation/monetarisation

In this chapter, the environmental impacts described in **chapter 7** are monetarised. As in **chapter 7**, the results are calculated using two different modelling approaches, i.e. the consequential approach (cause-effect based) and the attributional approach (normative/rule based). Results are shown using three different valuation methods:

- Stepwise
- Recommended valuation by the Danish EPA[6] (three different versions: low, aver., high)
- Trucost (two different versions: DK and global average)

8.1 Valuation using different methods

In the following, the valuation of results are presented using the three methods described in **section 3.5** and **3.6**. All results refer to the functional unit defined in **section 2.3**: "*Arla Foods' entire production in 2014, including upstream and downstream activities*".

An overview of the aggregated results from this is shown in **Figure 8.1**.

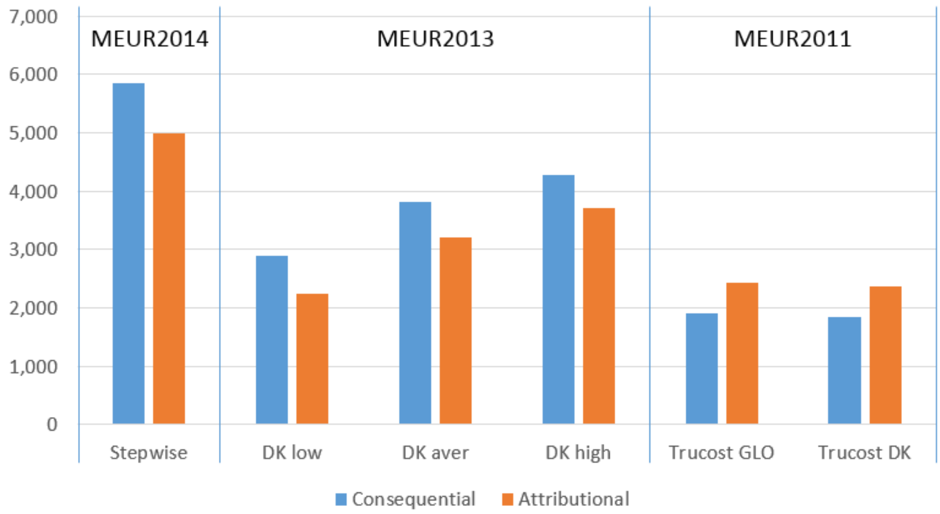

FIGURE 8.1: COMPARISON OF MONETARISED RESULTS USING ALTERNATIVE VALUATION METHODS.

It appears from **Figure 8.1** that the difference in monetarised results using alternative valuation methods is a factor three for the consequential results and a factor two for the attributional results. Given the fundamental differences between the methods, as described in **section 3.6**, these differences are relatively modest. A very small part of the differences is related to the fact that the different methods use slightly different currency years. The contributions to the overall monetarised results in **Figure 8.1** from elementary flows are shown in **Table 8.1** and **Table 8.2**.

[6] Referred to as the 'Danish Guidelines' in the following.

It should be noted that the results obtained using the Danish guidelines and the Trucost (DK) method apply valuation of emissions occurring in other countries than the methods are made for. Therefore, these results can only be used for obtaining an overall impression of how much different valuation methods affects the results.

In the detailed contribution tables in **Table 8.1** and **Table 8.2** below, it is indicated how much of the monetarised result calculated with the Stepwise method, that is caused by elementary flows not included in the other methods. For the consequential results this is 22% of the result (mainly related to nature occupation), and for the attributional results it is 3%.

The comparisons below show that the Stepwise method and Danish guidelines are in relative good agreement with regard to ammonia and NO_x, while the valuation of GHG emissions show significant differences. When comparing the Stepwise and Trucost methods, it appears that the valuation of ammonia and NO_x are significantly lower for the Trucost method, while there is better agreement with regard to GHG emissions.

TABLE 8.1: COMPARISON OF RESULTS USING ALTERNATIVE VALUATION METHODS (**CONSEQUENTIAL**).

Emissions	Stepwise (MEUR2014)	Danish Guidelines (MEUR2013)			Trucost (MEUR2011)	
		Low	Average	High	Global	Denmark
Ammonia (NH_3)	1,397	2,221	2,221	2,221	67	43
GHG emissions (CO_2-eq)	2,128	147	147	147	1,712	1,712
Carbon monoxide (CO)	6			<1		
Lead	1	<1	1	3		
Nitrogen oxides (NO_x)	571	219	644	644	54	24
NMVOC	3				8	4
Particulates	328	71	103	166	47	29
Sulphur dioxide (SO_2)	137	242	696	1,093	19	30
Sum of above emissions	**4,572**	**2,899**	**3,811**	**4,274**	**1,908**	**1,841**
Other elementary flows	1,280					
Total	**5,852**	**2,899**	**3,811**	**4,274**	**1,908**	**1,841**

TABLE 8.2: COMPARISON OF RESULTS USING ALTERNATIVE VALUATION METHODS (**ATTRIBUTIONAL**).

Emissions	Stepwise (MEUR2014)	Danish Guidelines (MEUR2013)			Trucost (MEUR2011)	
		Low	Average	High	Global	Denmark
Ammonia (NH_3)	937	1,489	1,489	1,489	45	29
GHG emissions (CO_2-eq)	2,903	193	193	193	2,255	2,255
Carbon monoxide (CO)	7			<1		
Lead	1	<1	1	2		
Nitrogen oxides (NO_x)	535	224	661	661	56	25
NMVOC	3				8	3
Particulates	274	60	86	140	39	24
Sulphur dioxide (SO_2)	154	271	780	1,225	21	34
Sum of above emissions	**4,814**	**2,238**	**3,210**	**3,711**	**2,425**	**2,370**
Other elementary flows	169					
Total	**4,984**	**2,238**	**3,210**	**3,711**	**2,425**	**2,370**

8.2 Contribution analysis

In the previous section it appeared, that the Stepwise methods included most emissions/exchanges and that no emissions in this method were valuated significantly lower than in the other methods. The method recommended by the Danish EPA showed significantly lower valuation of GHG emissions than the Stepwise and Trucost methods, and the Trucost method shoved significantly lower valuation of ammonia and NO_x than Stepwise and the Danish guidelines. Based on this, it has been chosen to present a contribution analysis in the following of which impacts and flows are contributing to the overall results using the Stepwise method.

Table 8.3 shows the monetarised results for the consequential and attributional approaches broken down into contributing impacts. The impacts are monetarised using the stepwise method as described in **section 3.5**.

TABLE 8.3: LIFE CYCLE IMPACT ASSESSMENT (LCIA) RESULTS: MONETARISATION/END-POINT EVALUATION WITH THE STEPWISE METHOD. UNIT: MILLION EUR2014.

	Monetarised results: Million EUR2014	
Impact category	**Consequential**	**Attributional**
Global warming	2,154	2,845
Respiratory inorganics	2,048	1,654
Nature occupation	986	-48
Eutrophication, terrestrial	259	181
Ecotoxicity, terrestrial	90	71
Human toxicity, carcinogens	79	49
Eutrophication, aquatic	70	49
Photochemical ozone, vegetat.	67	101
Human toxicity, non-carc.	45	33
Acidification	38	29
Ecotoxicity, aquatic	5	4
Respiratory organics	5	7
Mineral extraction	4	3
Total	**5,852**	**4,984**

The monetarised results express the damage caused by externalities related to Arla Foods product portfolio. The externalities can be compared to Arla Foods revenue at 10,600 million EUR2014, which indicate the created value.

It appears from **Table 8.3** that the results calculated using the consequential approach are higher than for the attributional approach. The major differences are seen for nature occupation and respiratory inorganics where the consequential results are highest. The reason why nature occupation is highest when using the consequential approach is that this is mainly caused by includes indirect land use changes (iLUC) which is not included in the attributional results. The reason why respiratory inorganics are higher for the consequential approach is also related to indirect land use changes, where ammonia emissions occur because of intensification of cropland. For global warming, the attributional results are highest. This is because the consequential approach includes the substituted beef production related to milk production, whereas the attributional approach allocates part of the milk production away to the beef by-product. The substituted beef are related to higher emissions in the consequential approach compared to the part that is allocated away in the attributional approach.

In the following, the monetarised results are described more in detail. This is done for both of the modelling assumptions.

8.2.1 Detailed monetarised results, consequential modelling

The overall monetarised impact is 5,852 million EUR2014. The breakdown of this result into contributing impacts is shown in **Figure 8.2** and **Table 8.4**.

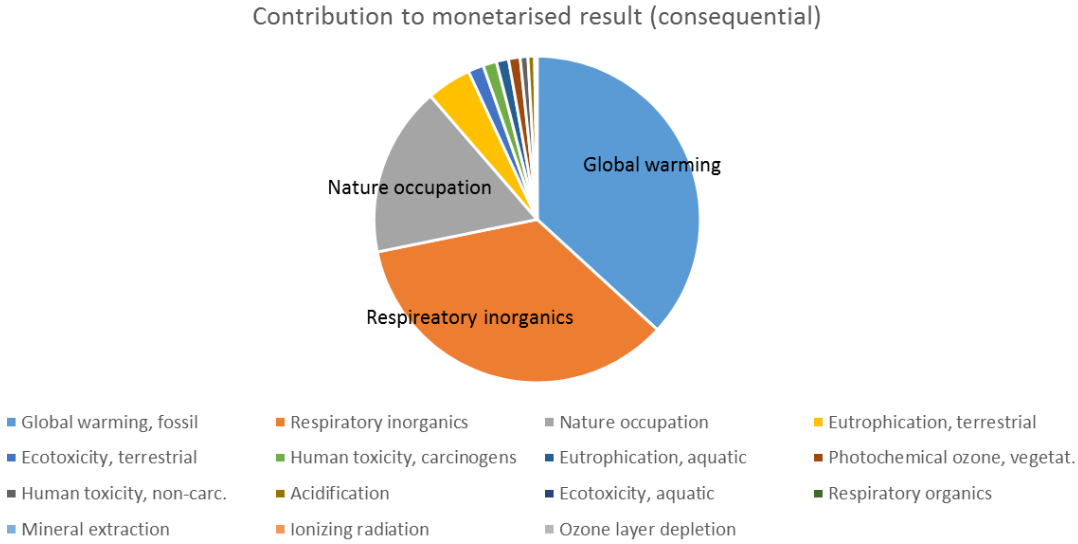

FIGURE 8.2: CONTRIBUTION TO THE MONETARISED IMPACT FROM DIFFERENT IMPACT CATEGORIES. MONETARISATION/END-POINT EVALUATION WITH THE STEPWISE METHOD.

Figure 8.2 shows that the most significant impact categories are global warming, respiratory inorganics and nature occupation. These three impact categories account for almost 90% of the total impact.

Below in **Table 8.4** the contributions to the most important impact categories are shown. The shown elementary flows (emissions and land use) account for more than 98% of the total monetarised impacts and the shown impact categories account for more than 99.9% of the total impact. It appears from the table that more than 80% of the total impact can be explained by seven elementary flows' contribution to only three impact categories. This means that a relevant holistic mitigation strategy can be targeted on very few elementary flows.

The negative contribution to nature occupation from 'Land occ: acc. denaturalisation, grassland to pasture' is related to the substituted beef production in grassland based systems. The substitution is caused by the beef by-product from the milk system.

TABLE 8.4: CONTRIBUTION ANALYSIS (CONSEQUENTIAL): IMPACTS AND ELEMENTARY FLOWS CONTRIBUTING TO THE MONETARISED RESULT –THE SEVEN MOST IMPORTANT ELEMENTARY FLOWS THAT TOGETHER CONTRIBUTE WITH MORE THAN 80% ARE HIGHLIGHTED WITH RED (INDICATES IMPACTS) AND GREEN (INDICATES AVOIDED IMPACTS).

Impact category	**Global warming**	**Respiratory inorganics**	**Nature occupation**	**Eutrophication, terrestrial**	**Ecotoxicity, terrestrial**	**Human toxicity, carcinogens**	**Eutrophication, aquatic**	**Photochemical ozone, vegetat.**	**Human toxicity, non-carc.**	**Acidification**	**Ecotoxicity, aquatic**	**Respiratory organics**	**Other impacts (<0.1% of total)**	**Total**
Land occ: acc. denaturalisation, sec. forest to arable			32%										0%	**32%**
Land occ: acc. denaturalisation, grassland to pasture			-14%										0%	**-14%**
Carbon dioxide, air (CO_2)	25%												0%	**25%**
Ammonia, air (NH_3)		19%		4%			0%		0%	1%			0%	**24%**
Nitrogen oxides, air (NO_x)		8%		0%				1%		0%		0%	1%	**10%**
Methane, air (CH_4)	8%							0%				0%	-1%	**8%**
Particulates, air ($PM_{2.5}$)		6%											0%	**6%**
Nitrous oxide, air (N_2O)	4%												0%	**4%**
Sulphur dioxide, air (SO_2)		2%								0%			0%	**2%**
Hydrocarbons, aromatic, air						1%					0%		0%	**1%**
Nitrate, water							1%						0%	**1%**
Copper, air					1%						0%		0%	**1%**
Other exchanges (<2% of total)	0%	0%	-1%	0%	1%	0%	0%	0%	1%	0%	0%	0%	0%	**1%**
Total	**37%**	**35%**	**17%**	**4%**	**2%**	**1%**	**1%**	**1%**	**1%**	**1%**	**0%**	**0%**	**0%**	**100%**

8.2.2 Detailed monetarised results, attributional modelling

The overall monetarised impact is 4,984 million EUR2014. The breakdown of this result into contributing impacts is shown in **Figure 8.3** and **Table 8.5**.

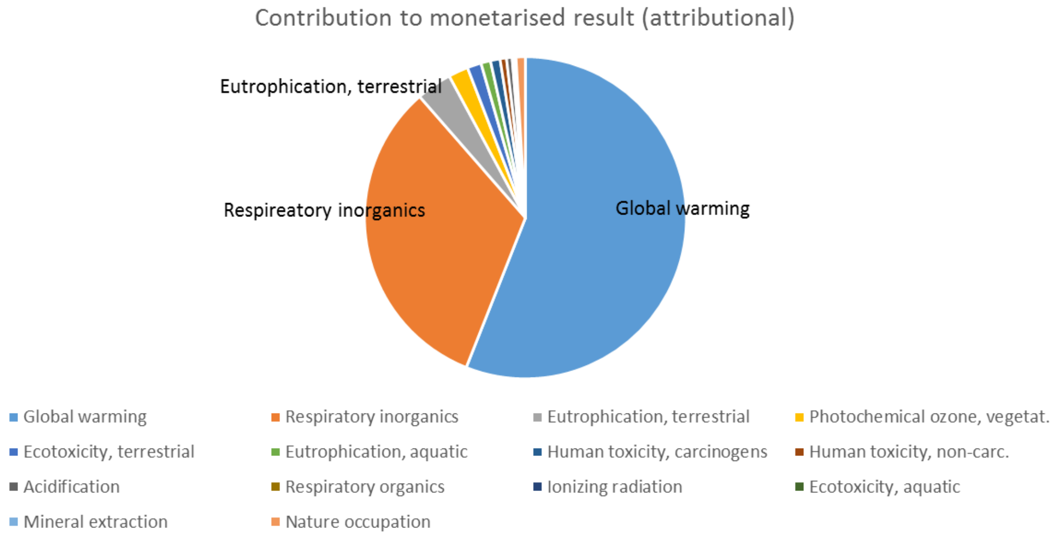

FIGURE 8.3: CONTRIBUTION TO THE MONETARISED IMPACT FROM DIFFERENT IMPACT CATEGORIES. MONETARISATION/END-POINT EVALUATION WITH THE STEPWISE METHOD.

Figure 8.3 shows that the most significant impact categories are global warming, respiratory inorganics and to a lesser extent terrestrial eutrophication. These three impact categories account for almost 95% of the total impact.

Below in **Table 8.5** the contributions to the most important impact categories are shown. The shown elementary flows (emissions and land use) account for more than 98% of the total monetarised impacts and the shown impact categories account for more than 99.8% of the total impact. It appears from the table that more than 80% of the total impact can be explained by five elementary flows' contribution to only two impact categories. This means that information on very few elementary flows is needed to represent the attributional results.

TABLE 8.5: CONTRIBUTION ANALYSIS (ATTRIBUTIONAL): IMPACTS AND ELEMENTARY FLOWS CONTRIBUTING TO THE MONETARISED RESULT – THE FIVE MOST IMPORTANT ELEMENTARY FLOWS THAT TOGETHER CONTRIBUTE WITH MORE THAN 80% ARE HIGHLIGHTED WITH RED.

Impact category	**Global warming**	**Respiratory inorganics**	**Eutrophication, terrestrial**	**Photochemical ozone, vegetat.**	**Ecotoxicity, terrestrial**	**Eutrophication, aquatic**	**Human toxicity, carcinogens**	**Human toxicity, non-carc.**	**Acidification**	**Respiratory organics**	**Ionizing radiation**	**Nature occupation**	**Other impacts (<0.2% of total)**	**Total**
Carbon dioxide, air (CO_2)	26%													**26%**
Methane, air (CH_4)	23%			1%						0%				**24%**
Ammonia, air (NH_3)		15%	3%		0%	0%		0%	0%					**19%**
Nitrogen oxides, air (NO_x)		10%	0%	1%					0%	0%				**11%**
Nitrous oxide, air (N_2O)	8%					0%								**8%**
Particulates, air ($PM_{2.5}$)		6%												**6%**
Sulphur dioxide, air (SO_2)		3%							0%					**3%**
Hydrocarbons, aromatic, air							1%							**1%**
Nitrate, water						1%								**1%**
Copper, air					1%									**1%**
Occupation, pasture and meadow, extensive												-1%		**-1%**
Other exchanges (<2% of total)	0%	0%	0%	0%	1%	0%	0%	1%	0%	0%	0%	0%	0%	**2%**
Total	**57%**	**33%**	**4%**	**2%**	**1%**	**1%**	**1%**	**1%**	**1%**	**0%**	**0%**	**-1%**	**0%**	**100%**

9. Discussion and conclusions

9.1 Goal, scope and methods

To document the total life cycle environmental impact of its product portfolio, Arla Foods is conducting an Environmental Profit and Loss Account (E P&L). The E P&L expresses Arla Foods' environmental impacts in monetary units, in addition to the underlying physical units. Arla Foods intends to use the results to evaluate their environmental strategy 2020 in order to assure that its focus is put on priority areas. Furthermore, the findings are intended to be used in various communications and it is an important step towards showing that Arla takes its environmental commitment seriously and takes responsibility for the whole value chain.

The unit of analysis is the sum of all Arla's activities in 2014. Hence, the E P&L includes all environmental life cycle impacts from cradle to grave of the sum of all Arla's products for the financial year 2014. The included product system is illustrated in **Figure 9.1**.

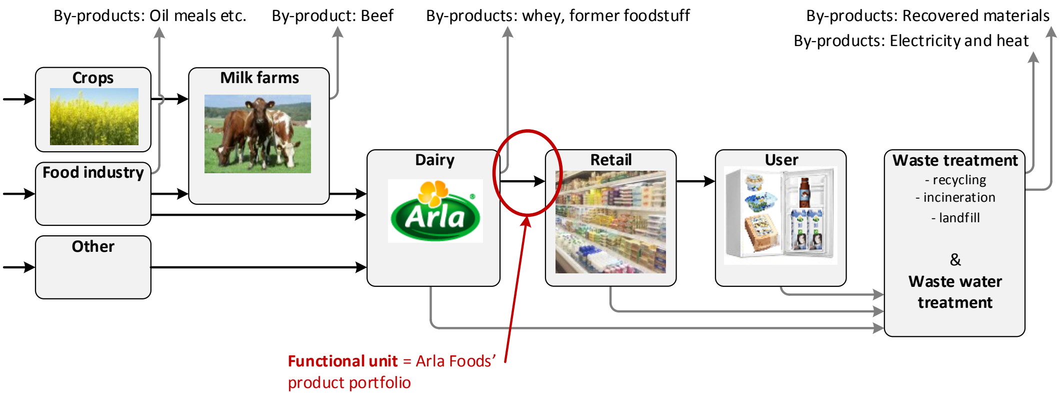

FIGURE 9.1, OVERVIEW OF THE PRODUCT SYSTEM RELATED TO ARLA FOODS' PRODUCTION. THE GREY ARROWS REPRESENT BY-PRODUCTS AND WASTE FLOWS.

Arla Foods' product portfolio in 2014 includes 7.68 million tonne dairy products and 1.32 million tonne by-products (whey and former foodstuff that is sold as animal feed). Out of the 7.68 million tonne dairy products, 5.55 million tonne is fresh dairy products (milk, yogurts, cream etc.) and 0.68 million tonne is cheese. The rest is whey/milk powder, butter and spreads, and non-milk based products (mainly fruit juice).

The E P&L includes activities for the whole company, including the daughter companies Arla Foods Ingredients, Rynkeby and Cocio, but excluding joint ventures. All Arla foods production sites, distribution centres and administrative units (99 sites in 12 countries) are part of the study. Production and use of raw materials, energy carriers, packaging and transport (inbound and outbound) are included, as well as treatment and utilization of by-products and wastes. In addition, products and services not directly used in production, such as computers, furniture and travelling are covered. The downstream parts of the life cycles (retail and consumers) are also included.

In order to calculate the life cycle emissions, life cycle assessment (LCA) is used. LCA is a method where all emissions and resources from all activities in a life cycle product system are added. Based on these life cycle emissions and resources, the life cycle impact results can be calculated. Results are presented at mid-point in physical units as well as at end-point in monetary units. Mid-point results include e.g. global warming, respiratory effects, nature occupation (biodiversity), and end-point results are calculated as the sum of impacts on human health, ecosystems and resources in monetary unit.

When calculating the life cycle emissions and resources, two different approaches for LCA is commonly used: the consequential approach and the attributional approach. The results are presented using both approaches. **Box 9.1** briefly explains the different focus of the two approaches.

> **Two LCA methods, two sets of results, answers to two different questions**
> **Consequential LCA** gives an answer on the question: "*what is the impact of a choice*?" This choice could be to buying or producing a product, or to implementing an improvement option. Consequential LCA is relevant when Arla wants to know the impacts of their actions.
> **Attributional LCA** gives an answer on the question: "*what are the impacts from that part of the life cycle that it has been decided to include based on the normative allocation and cut-off rules?"* Attributional LCA is relevant when Arla wants to report their impacts according to consensus based guidelines/standards.

BOX 9.1 CONSEQUENTIAL ANDATTRIBUTIONAL LCA – TWO WAYS OF MODELLING A PRODUCT SYSTEM IN LCA.

The inventory of the life cycle of Arla Foods' products takes into account that the use of land for animal feed contributes to the pressure on lands and thereby to transformation of unproductive (natural) land into productive land. This most often take place in other regions of the world than where the actual animal feed is grown. The transformation of land from e.g. forest to agricultural land implies a change in the biodiversity of the land as well as a change in the carbon stock of the land, which in turn leads to CO_2 emissions. This contribution to biodiversity impacts and CO_2 emissions is referred to as indirect land use changes (iLUC). Since it is not common to including indirect land use changes in attributional LCA, iLUC is only included in the consequential results.

When calculating the mid-point and end-point results, this is based on the Stepwise method (Weidema et al. 2007; Weidema 2009). The Stepwise method uses commonly acknowledged methods for calculating mid-points, e.g. global warming is calculated using IPCC's global warming potential (GWP100). The valuation step in LCA is less commonly applied, and therefore there is no generally acknowledged methods for this step. As a sensitivity analysis, the valuation is also carried out by using the recommended guidelines by the Danish EPA and the method developed by Trucost, which was used in previous studies published by the Danish EPA.

9.2 Main findings

By using the valuation in the Stepwise method, the following impact categories related to the life cycle of Arla Foods' product portfolio in 20114 were identified as the most significant:

- Global Warming (CO_2, CH_4, N_2O)
- Respiratory inorganics (air emissions: particles, ammonia, NO_x, SO_2)
- Nature occupation (biodiversity)

The attributional results showed that terrestrial eutrophication were also important (though less than global warming and respiratory inorganics).

The importance of the impacts listed above were confirmed by other weighting methods for life cycle impact assessment (LCIA) as well as other valuation methods. The other LCIA methods point at the use of non-renewable energy as another important impact category. In addition to the impact categories mentioned above, mid-point results are also shown for water use and land occupation. These impacts are not monetarised in the valuation step; land occupation is an intermediate flow linking land use and land use changes (only land use changes are monetarised), and water use is not included in the monetarisation in Stepwise.

9.2.1 Results presented as mid-point impacts in physical unit

The contribution to the key impacts mentioned above are summarised in **Table 9.1**.

TABLE 9.1: CONTRIBUTION TO KEY IMPACT CATEGORIES AT MID-POINT. RESULTS ARE SHOWN FOR TWO MODELLING ASSUMPTIONS IN THE LIFE CYCLE INVENTORY: CONSEQUENTIAL (CAUSE-EFFECT BASED) AND ATTRIBUTIONAL (NORMATIVE/RULE BASED).

Impact category	Unit	Indicator results	
		Consequential	Attributional
Stepwise. These impacts are monetarised			
Global warming	million tonne CO_2-eq	20.2	26.6
Respiratory inorganics	tonne $PM_{2.5}$-eq	23,551	19,018
Nature occupation	PDF*ha*year	544,000	-26,000
Non-renewable energy	TJ primary	136,000	164,000
Additional impacts. These impacts are not monetarised			
Land occupation	million ha	-3.63	2.74
Water use, blue water footprint	million m^3	194	293

The majority of the impacts are related to activities in agriculture: animal and feed production. Hence, the contribution analysis showed that 59% (consequential) and 62% (attributional) of the total life cycle GHG emissions related to Arla Foods' product portfolio were related to the production of raw milk. Milk production was also dominating for the other impact categories – except nature occupation in the attributional results, which show a small negative result. The reason for this is that the attributional results do not include indirect land use changes, which is where the majority of the biodiversity impact is occurring. Attributional results only include the direct land use effects. Since extensive pastures used for milk cattle host more biodiversity than the alternative use of such lands, the direct land use effects become negative.

Another negative result that deserves some comments is land occupation in the consequential results. The reason why this is negative is that the consequential modelling includes all the land uses relating to milk production and subtracts all the land uses related to the by-product of milk production, i.e. the beef. Hence, the negative result involves a positive contribution in the milk and feed producing countries and a negative contribution in Brazil, which is regarded as the marginal supplier of beef. The reason why the net land use becomes negative is that the substituted beef system in Brazil is very extensive, i.e. the animal density on the affected grasslands is very low. It should also be noted that the total impact on nature occupation (biodiversity) is not negative. This is because the substituted occupation of grassland does not have as high an impact on nature occupation as occupation of arable land.

A detailed analysis of the contributions to the different impact categories can be found in **chapter 7**.

9.2.2 Results presented and monetarised impacts

The monetarised results express the damage caused by externalities related to Arla Foods product portfolio. The monetarised impacts, i.e. the investigated externalities, can be compared to Arla Foods revenue at 10,600 million EUR2014, which indicate the created value.

When monetarising the impacts, the consequential and attributional approaches show a contribution at 1840-5850 and 2240-4980 million EUR, respectively. The intervals represent results obtained using different valuation methods. It appears that the results highly depend on the choice of valuation method. In **Table 9.2** below, the monetarised results obtained using the different valuation methods are explained.

The conclusion is that Stepwise shows the highest results. This is because GHG emissions, ammonia and nature occupation are associated with high costs. The valuation method recommended by the

Danish EPA shows lower results than Stepwise because GHG emissions are associated with low costs (based on CO_2 quota prices) and because nature occupation is not valuated. Trucost's method shows lower results than Stepwise because ammonia is associated with low costs and because nature occupation is not valuated.

Generally, the consequential approach shows higher results than the attributional approach because indirect land use changes are included. This causes significant impacts on e.g. nature occupation (biodiversity).

TABLE 9.2. EXPLANATION OF MONETARISED RESULTS OBTAINED BY USING DIFFERENT METHODS. THE INTERVALS REPRESENT DIFFERENT VERSIONS OF THE VALUATION METHODS.

Method	Results Million EUR	Explanation
Stepwise		
- Consequential LCA	5850	High contribution: GHG emissions, ammonia and nature occupation Low contribution: None
- Attributional LCA	4984	High contribution: GHG emissions, ammonia Low contribution: Nature occupation
Valuation recommended by the Danish EPA		
- Consequential LCA	2900-4270	High contribution: Ammonia Low contribution: GHG emissions (nature occupation is not valuated)
- Attributional LCA	2240-3710	
Trucost		
- Consequential LCA	1840-1910	High contribution: GHG emissions Low contribution: Ammonia (nature occupation is not valuated)
- Attributional LCA	2370-2430	

9.3 Sensitivity, completeness and consistency

This E P&L account make use of very large amounts of data and models. Therefore, the results are also associated with uncertainties. The robustness of the results is assessed in this section by focussing on sensitivity, completeness and consistency of data and modelling assumptions. The assessment is divided into life cycle inventory, life cycle impact assessment (mid-point), life cycle impact assessment (end-point) i.e. valuation.

9.3.1 Life cycle inventory

The major contributor to the overall impact (mid-point as well as monetarised) is the production of raw milk which is the main raw material used at Arla Foods. Therefore, it is relevant to focus on the data and modelling applied for this. The production of raw milk is based on detailed life cycle inventories of national averages for Denmark, Germany, Sweden and United Kingdom for 2012 (Dalgaard et al. 2015b). This study was initiated already in 2011 with the creation of Danish and Swedish milk baselines for GHG emissions (Dalgaard and Schmidt 2012b; Schmidt and Dalgaard 2012a).

The milk studies referred to above make use of national and international statistical material as well as consultations with national specialists in milk production in Denmark, Germany, Sweden and United Kingdom. The studies are also the background for a farm calculator, which is used by Arla Foods to evaluate the GHG emissions from the farms supplying raw milk. The collected data from more than 100 farms has been used to calibrate key data inputs for the national milk baselines.

The milk studies uses exactly the same modelling choices and system boundaries as used in the current E P&L. Therefore, the level of consistency is very large. However, there are two points of inconsistencies: 1) Since Arla Foods uses milk from other countries than the four included countries in the milk study, there is not full representability of the data. However, this only concerns 4% of Arla Foods' use of raw milk. This is modelled as an average of the four included countries. 2) The country baselines are for 2012, while the current study is for 2014. The introduced uncertainties related to the two inconsistencies above are regarded as insignificant.

The major uncertainties related to the national baselines of milk are related to model uncertainty of methane emissions and nitrous oxide emissions from agriculture (IPCC model has been used), data on the use of animal feed and fertiliser use. More information can be found in Schmidt and Dalgaard (2012a).

Effects from indirect land use changes are included in the consequential results. This alone accounts for e.g. 27% of the GHG emissions of the consequential results. The modelling of indirect land use changes is associated with significant uncertainties. The major uncertainties relate to distribution between land transformation and intensification, emissions from land transformation, emissions from intensification.

All data related to inputs and outputs of products, emissions and wastes from Arla Foods' production sites are based on Arla's environmental accounting system (physical flows) and financial accounting system (other transactions, measured in monetary unit). These data are regarded as having a high level of detail: the data are complete and they are associated with small uncertainties.

The downstream activities; retail, consumption and waste treatment are based on European average data. A top-down approach has been used to identify the amount of retail inputs (e.g. energy), transport from retail to end-user, inputs in households (e.g. electricity for cold storage and dishwashing) and waste to treatment. This involves some uncertainties when relating the total European flows in retail and households to dairy products. This part of the inventory is regarded as the most uncertain. Since these life cycle stages account for a relatively small part of the overall results, the sensitivity of results related to these uncertainties is small.

9.3.2 Life cycle impact assessment (mid-point)

A broad range of impact categories is included in the study. The impacts are modelled using impact pathways from the best available models. Of the commonly included impacts in life cycle assessment, only ozone depletion has been excluded (due to lack of data). Other potential important impacts that are not included are: social impacts (e.g. nutritional effects, income redistribution impacts), effects caused by release of animal medicine residues, and heavy metal emissions to soil from contaminants in fertilisers.

The current study includes an update of the way to model nature occupation (biodiversity) in life cycle impact assessment. This is made consistent with the way indirect land use changes are modelled.

9.3.3 Life cycle impact assessment (end-point / valuation)

Valuation of emissions or impacts is associated with uncertainties. This is clearly underpinned with the relatively large ranges of monetarised results using the three different valuation methods.

The major uncertainties of the Stepwise method, which is used for monetarising the impacts are the data and assumption used for identifying the monetary value of a QALY (quality adjusted life year) and the value of ecosystems relative to QALY. Furthermore, the current version of Stepwise does not use discounting.

The valuated impacts do not include social impacts, effects caused by release of animal medicine residues, heavy metal emissions to soil from contaminants in fertilisers, and the use of water.

The monetarised results calculated using the Stepwise method were compared with results calculated using alternative valuation methods; the method recommended by the Danish EPA and a method developed by Trucost. Since, valuation of impacts is in general associated with high uncertainties; the purpose of this comparison was to obtaining an overall impression of how much different valuation methods affects the results. It should be noted that the results obtained using the Danish guidelines and the Trucost (DK) methods apply valuation of emissions occurring in other countries than the methods are made for. Therefore, the results for alternative valuation are associated with inconsistencies and before being used for any decision support, adequate reservations should be made.

The calculations with the Danish guidelines and the Trucost method showed results, which were between 30% and 75% of the results obtained with the stepwise method. The largest difference was seen for the consequential results – this is because the alternative methods do not include valuation of nature occupation impacts. Other reasons for higher results with the Stepwise method are mainly related to lower valuation of GHG emissions in the Danish guidelines (these are based on market price of CO_2 quota) and lower valuation of ammonia emissions in the Trucost method.

9.3.4 Robustness of results

Overall, the data, modelling assumptions and impact assessment for results in physical unit, are regarded as having a high level of consistency and completeness. Relatively large differences are seen for results obtained using the consequential and attributional approaches. However, since the two approaches are used for answering different questions, this is expected. The major uncertainties are related to uncertainties in data with regard to indirect land use changes and emission models (enteric fermentation and field emissions). For the valuation of the impacts, larger uncertainties and dependencies of choice of methods are seen.

9.4 Conclusion and outlook

This E P&L account is the first of its kind for the food sector. The results are calculated based on comprehensive data collection and life cycle assessments. The results show that both the value (Profit) and the impacts (Loss) of Arla Foods production and subsequent distribution and consumption of their products are high. The E P&L account gives a broad and deep insight in the impacts from the full life cycle of Arla Foods product portfolio and the underlying contributions. Hence, it provides a good basis for more comprehensive sustainability reporting and for identifying options for improving the performance and reducing the impact.

The contribution analysis of the causes of the overall monetarised impact showed that a very large share can be explained by few emissions, few impact categories and few life cycle stages. Hence, the E P&L can help focussing on the most important impacts. Furthermore, the account can be used as a baseline to which different improvement options are evaluated.

The E P&L account has been compiled using two different approaches: consequential and attributional. The results from each approach can be used for different purposes. The consequential approach should be used, when information from the E P&L is intended for decision support (directly or indirectly) and when knowledge of the impact of different actions is sought. The attributional results are relevant when results need to be reported according to a common and normative reference; here the International Dairy Federation Guideline on life cycle assessment.

The results for monetarised impacts showed to be highly dependent on the choice of valuation method. This points at the need for more research and more scientific consensus of how to monetarise environmental impacts.

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Appendix 1: Fuel and dairy product properties

TABLE A1: FUEL PROPERTIES.

Fuel	**Density (kg/litre)**	**Calorific value (MJ/kg)**	**Calorific value (MJ/kg)**
Diesel[1]	0.832	43.1	35.9
Rapeseed methyl ester (RME) [1]	0.890	37.2	33.1
BIO+[1]	0.826	42.8	35.4
Liquefied natural gas (LNG) [1]	0.450	45.1	20.3
Liquefied bio methane (LBM) [1]	0.450	48.9	22.0
Petrol	0.720	42.7	30.7

[1] Data are obtain from Arla's emission accounting system.

TABLE A2: AMOUNTS AND DRY MATTER PERCENTAGES OF ARLA'S PRODUCT PORTFOLIO IN 2014. THE DRY MATTER PERCENTAGES ARE OBTAINED FROM WHOLEFOODCATALOG (2015B), EXCEPT FOR WHEY WHICH IS CALCULATED BASED ON A MASS BALANCE, SEE **FIGURE 4.1**.

Arla products	Amount (tonne wet weight)	Main product	Dry matter percentage
Fresh dairy products (milk, yogurts, cream…)	5,551,000	x	12%
Whey for animal feed	1,232,000		5.2%
Cheese	680,000	x	60%
Powder	501,000	x	90%
Whey powder	493,000	x	90%
Butter and Spread	274,000	x	84%
Non milk based products (mainly fruit juice)	181,000	x	30%
Former Foodstuff (animal feed)	87,000		30%
Total main products	**7,680,000**	**85%**	**29%**
Total by-products	**1,319,000**	**15%**	**6.8%**
Total	**8,999,000**	**100%**	**26.0%**

Appendix 2: Numerical example of land use changes

Below a numerical example of the calculation of the biodiversity global warming impact of 1 ha*year unfertilised grassland in Denmark is presented.

In **Figure 0.1**, the permanent grass LCA activity (to the right) is linked with the iLUC model (activity in the middle and two activities to the left). The permanent grass activity has input of 'land tenure'. This flow links to the iLUC model (Schmidt and Muñoz 2014; Schmidt et al. 2015). The input is 1.15 ha*year equivalents because Danish arable land has 15% higher potential yields (measured as potential net primary production) compared to global average arable land. The activity in the middle of **Figure 0.1** is the market for land. This activity specifies how much of an additional unit of demand for land that is supplied by expansion of arable land and intensification of existing land respectively. To the left are the two activities representing expansion of arable land and intensification of land. The numbers in **Figure 0.1** are described in **Figure 0.2**.

Land use changes

Output	Flow	Unit
Expansion	1.15*37%	ha*year eq.
Ressource inputs from nature		
Occupation, accelerated denaturalisation, secondary forest to arable	1.15*37%*(6,940/6,110)	ha*year
Emissions		
Accelerated CO_2	1.15*37%*(6,940/6,110)*433	ton

Intensification

Output	Flow	Unit
Intensification	1.15*63%	ha*year eq.
Inputs from technosphere		
N-Fertiliser, as N	1.15*63%*94	kg
Emissions		
N_2O	1.15*63%*2.1	kg

Land market activity

Output	Flow	Unit
Land tenure	1.15	ha*year eq.
Inputs from technosphere		
Expansion	1.15*37%	ha*year eq.
Intensification	1.15*63%	ha*year eq.

Permanent grass LCA activity (1 ha*year)

Output	Flow	Unit
Roughage, permanent grass {DK}	11,628	kg
Inputs from technoesphere		
Land tenure	1.15	ha*year eq.
Diesel for traction	557	MJ
N-Fertiliser, as N	85	kg
Emissions		
N_2O	2.66	kg
Resources		
Occupation, pasture and meadow, extensive	1	ha*year

Grass

FIGURE 0.1, EXAMPLE FIG. 1: BIODIVERSITY AND GLOBAL WARMING FROM 1 HA*YEAR PERMANENT GRASS CULTIVATED ON ARABLE LAND. THE PERMANENT GRASS LCA ACTIVITY (TO THE RIGHT) IS LINKED WITH THE ILUC MODEL (ACTIVITY IN THE MIDDLE AND TWO ACTIVITIES TO THE LEFT).

*Permanent grass LCA activity (1 ha*year)*

Output	Flow	Unit
Roughage, permanent grass {DK}	Annual yield of grass	kg
Inputs from technoesphere		
Land tenure	Productivity of 1 ha in DK relative to 1 ha average	ha*year eq.
Diesel for traction	Diesel use for maintaining/ collecting grass	MJ
N-Fertiliser, as N	Amount of fertiliser for permanent grass	kg
Emissions		
N_2O	Field emissions	kg
Resources		
Occupation, pasture and meadow, extensive	Exchange that causes direct land use changes	ha*year

→ Grass

Land use changes

Output	Flow	Unit
Expansion	37% of new crop production comes from expansion	ha*year eq.
Ressource inputs from nature		
Occupation, accelerated denaturalisation, secondary forest to arable	New land has higher productivity than average land => (6,940/6,110)	ha*year
Emissions		
Accelerated CO_2	The land above is multiplied by 433 t CO_2/ha. Carbon stocks of arable and forests are 27 t C and 145 t C respectively. The change is 118 t C *44/12 = 433 t CO2.	ton

Land market activity

Output	Flow	Unit
Land tenure	Productivity of 1 ha in DK relative to 1 ha average	ha*year eq.
Inputs from technosphere		
Expansion	37% of new crop production comes from expansion	ha*year eq.
Intensification	63% of new crop production comes from intensification	ha*year eq.

Intensification

Output	Flow	Unit
Intensification	63% of new crop production comes from intensification	ha*year eq.
Inputs from technosphere		
N-Fertiliser, as N	The land above is multiplied with 94 kg N-fert/ha*year land from intensification	kg
Emissions		
N_2O	The land above is multiplied with 2.1 kg N_2O emission/ha*year land from intensification	kg

FIGURE 0.2, EXAMPLE FIG. 2: BIODIVERSITY AND GLOBAL WARMING FROM 1 HA*YEAR PERMANENT GRASS CULTIVATED ON ARABLE LAND. THIS FIGURE EXPLAINS THE NUMBERS IN **FIGURE 0.1**.

*Permanent grass LCA activity (1 ha*year)*

Output	Flow	Unit
Roughage, permanent grass {DK}	nual yie	kg
Inputs from technosphere		
Land tenure	1.15	ha*year eq.
Diesel for traction	557	MJ
N-Fertiliser, as N	85	kg
Emissions		
N_2O	2.66	kg
Resources		
Occupation, pasture and meadow, extensive	1	ha*year

→ Grass

Land use changes

Output	Flow	Unit
Expansion	0.43	ha*year eq.
Ressource inputs from nature		
Occupation, accelerated denaturalisation, secondary forest to arable	0.48	ha*year
Emissions		
Accelerated CO_2	209	ton

Land market activity

Output	Flow	Unit
Land tenure	1.15	ha*year eq.
Inputs from technosphere		
Expansion	0.43	ha*year eq.
Intensification	0.72	ha*year eq.

Intensification

Output	Flow	Unit
Intensification	0.72	ha*year eq.
Inputs from technosphere		
N-Fertiliser, as N	68	kg
Emissions		
N_2O	1.5	kg

FIGURE 0.3, EXAMPLE FIG. 3: BIODIVERSITY AND GLOBAL WARMING FROM 1 HA*YEAR PERMANENT GRASS CULTIVATED ON ARABLE LAND. THIS FIGURE SHOWS THE CALCULATED FLOWS FROM **FIGURE 0.1**.

In **Table 0.1**, the relevant flows to calculate land use related impacts on biodiversity GHG emissions are listed (obtained from **Figure 0.3**), and the mid-points are calculated. It should be noted that the use of 68 kg N-fertiliser in **Figure 0.3** has been transformed to 269 kg CO_2-eq. by using 3.95 kg CO_2-eq/kg N (calculated using data from the ecoinvent database). In the calculation of GHG emissions, it has been assumed that the carbon stock of 1 ha permanent grass is equal to 1 ha average arable land.

TABLE 0.1: CALCULATION OF BIODIVERSITY AND GHG EMISSION IMPACTS USING THE FLOWS FROM **FIGURE 0.3** AND THE CHARACTERISATION FACTORS FOR BIODIVERSITY IN THE STEPWISE METHOD (**TABLE 3.3**) AND FOR GHG EMISSIONS IN THE GWP100 METHOD (IPCC 2013). THE CHARACTERISATION FACTOR FOR ACCELERATED CO_2 IS DOCUMENTED IN SCHMIDT ET AL. (2015).

Flows	Flow calculated in life cycle inventory	Characterisation factor	Mid-point indicator result
Biodiversity impact			
Occupation, pasture and meadow, extensive	1 ha*year	-0.09 PDF*ha*year / ha*year	-0.09 PDF
Occupation, accelerated denaturalisation, secondary forest to arable	0.48 ha*year	0.8 PDF*ha*year / ha*year	0.39 PDF
Total			**0.30 PDF**
GHG impact (GWP100)			
Accelerated CO_2	177,000 kg	0.0078 kg CO_2-eq/kg acc. CO_2	1,632 kg CO_2-eq
N_2O	1.5 kg	265 kg CO_2-eq/kg N_2O	403 kg CO_2-eq
CO_2-eq from fertiliser production	269 kg	1 kg CO_2-eq/kg CO_2-eq	269 kg CO_2-eq
Total			**2,305 kg CO_2-eq**

Arla Foods Environmental Profit and Loss Accounting 2014
Som et led i dokumentationen af miljøpåvirkninger fra deres samlede produktportefølje har Arla Foods fået udarbejdet en Environmental Profit and Loss Account (E P&L). Analysen fokuserer på miljøpåvirkningen fra alle Arla's aktiviteter i 2014. Således inkluderes alle livscykluspåvirkninger fra vugge til grav fra summen af hele Arla Foods produktportefølje i 2014.

To document the total life cycle environmental impact of their product portfolio, Arla Foods is conducting an Environmental Profit and Loss Account (E P&L. The unit of analysis is the sum of all Arla's activities in 2014. Hence, the E P&L includes all
environmental life cycle impacts from cradle to grave of the sum of all Arla's products for the financial year 2014.

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