PREFACE

This report is my master thesis for the conclusion of my Master program at the Center for Energy and Environmental Sciences (IVEM), University of Groningen. Moreover, it is also a conclusion of my internship at the Sustainable Agriculture Department, Unilever Corporate Centre. I really appreciated many people who helped me at the project.

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Today I finished my report and I will continue to challenge myself in the future with what I learned. This is not the end but only the start.
# TABLE OF CONTENTS

**SUMMARY** ................................................................................................................................. 5  
**1. INTRODUCTION** .......................................................................................................................... 7  
**2. RESEARCH PLAN** .......................................................................................................................... 9  
  2.1 Research aim ................................................................................................................................. 9  
  2.2 Research questions ........................................................................................................................ 9  
  2.3 Boundaries ....................................................................................................................................9  
  2.4 Methods and data .......................................................................................................................... 9  
**3. PRESENT MARKET, ICE CREAM PRODUCTION SYSTEM IN CHINA** ..................... 11  
  3.1 Present ice cream market in China ..............................................................................................11  
  3.2 Present ice cream production of Unilever in China .................................................................11  
  3.3 System descriptions of ice cream ..............................................................................................12  
    3.3.1 Dairy farming systems ........................................................................................................13  
    3.3.2 Raw materials for ice cream production ...........................................................................15  
    3.3.3 Making ice cream in factories ..........................................................................................15  
    3.3.4 Distributing ice cream ........................................................................................................15  
    3.3.5 Transportation within the supply chain .............................................................................15  
    3.3.6 Some omitted stages .............................................................................................................16  
**4. METHODOLOGIES AND DATA** ..........................................................................................17  
  4.1 Methodologies .............................................................................................................................17  
  4.2 Data applied to scenario analyses ..............................................................................................18  
**5. INTEGRATED RESULTS** ......................................................................................................23  
  5.1 Carbon footprint of ice cream .....................................................................................................24  
  5.2 Energy use of ice cream ..............................................................................................................26  
  5.3 Conventional or organic dairy farming and consequent on-farm emissions of ice cream ..........26  
  5.4 Energy required for future ice cream consumption patterns in China .......................................27  
**6. OPTIONS AND DISCUSSIONS** .........................................................................................29  
  6.1 Mitigating on-farm GHG emissions ............................................................................................29  
  6.2 Changing energy mix ..................................................................................................................29  
  6.3 Planning the target market .........................................................................................................30  
  6.4 Using liquid milk instead of milk powders ...............................................................................30  
**7. CONCLUSIONS AND RECOMMENDATIONS** .....................................................................31  
  7.1 Conclusions ...............................................................................................................................31  
  7.2 Recommendations for future study ..........................................................................................31  
**REFERENCES** .............................................................................................................................33
APPENDICES ........................................................................................................................................37

Appendix 1 Distribution of dairy processing enterprises ...................................................................37
Appendix 2 Distance of transporting milk powders ........................................................................38
Appendix 3 Melamine Issue 2008 in China ....................................................................................40
Unilever is planning to expand its ice cream production based on current conditions in China. Production expansion means increasing demands of raw materials e.g. milk powders, and requirements of energy use for processing, transporting and storing. From producing fresh milk for milk powders till storing ice cream in freezer cabinets, the ice cream chain implies large amounts of greenhouse gas (GHG) emissions. As a multi-national corporation with strong social responsibilities and one of the leading ice cream manufacturers in China, Unilever would like to assess and mitigate GHG emissions from the perspective of ice cream supply chain. Carbon footprint is the term applied in the study to evaluate global warming potential (GWP) of ice cream chain.

Unilever has done several relevant researches focusing on Europe. Due to data and information gaps between available approaches over European production and China’s conditions, this study was conducted through dividing its whole chain into several stages from dairy cows on farms till storage at selling points. Mass balance approach and scenario analyses were used to gain insight into the climate impacts hotspots of the ice cream chain for Unilever in China. In the meanwhile, an overview of sub-systems concerned in the study, e.g. dairy farming systems and milking systems, was concisely explained. Next to that, integrated scenario results were shown over what the carbon footprint of one litre ice cream is, and what options could decrease it.

Overall, the carbon footprint of ice cream (only based on milk, excluding other ingredients) in China is 1.2-1.8 kg CO$_2$ equivalent per litre and energy use is 5.8-10.5 MJ per litre. Three stages of milk production on farms, manufacturing in plants and storing at selling points were found to be the GHG hotspots of the chain. The GWP mainly resulted from fossil fuels combustion for transportation and generation of electricity after the farm-gate. Carbon dioxide is the main GHG which has a significant influence on and contributes about 80% to the total carbon footprint. Distributing ice cream to selling points with various distances may result in more emissions.

Considering the complexity, general conclusions with regard to mitigating GHG emissions of the ice cream chain were drawn. Therefore, the most effective and pragmatic measures to decrease the climate impact of ice cream from the perspective of ice cream chain for Unilever would be the following: mitigating the GHG emissions from dairy farms through effective manure management, replacing utilization of milk powders with liquid milk, planning the point of manufacturing to market served, and transforming energy mix through utilization of green energy.

This study did not come up with concrete policy recommendations but rather identifies a number of issues that merit further tailor-made investigations based on practical conditions in China. It will also contribute to a more detailed debate on policy proposals within different divisions of Unilever.
1. INTRODUCTION

Historically, dairy and milk-based products were rare in China because of a high incidence rate of lactose intolerance, low level of milk and dairy production, and no cultural history of cheese and other dairy products. Plus other existing obstacles, such as the transportation problems, southern climate, poor storage and packaging, dairy products were not the easiest things to produce and sell either for local or international companies.

However, China is changing rapidly and so are its tastes. As a consumer society emerges, so new products are appearing with increasing regularity. Dairy products are among them. Rising average annual incomes, greater ownership of fridges and freezers, increased exposure to western and international cuisines and a greater array of goods in the supermarket are all combining to increase sales of dairy products in China.

Ice cream is one of the popular dairy products in western countries. It is a frozen dessert made of milk, sugar, cream combined with fruits or other ingredients and flavours. Per capita, Australians, New Zealanders and Americans are among the leading ice cream consumers in the world, eating 18 to 23 litres per year, while the average ice cream consumption is only around 1.9 litres per capita per year in China (University of Guelph, 2009), and is expected to grow to 6 litres in 20 years (China Daily, 2004). In addition, ice cream consumption still has an obvious seasonal character on consumption in China (Zhang, 2008), and the major ice cream consumers are Chinese aged between 15 and 29, who like to try new products and are not overly concerned about price (China Daily, 2004). With the enhanced living standard and changed tastes of Chinese people, the ice cream industry holds great promises of opportunities and potentials in China.

Unilever is planning to expand its ice cream production in China. In the meanwhile, as a multinational corporation with strong social responsibilities and one of the leading ice cream manufacturers in China, Unilever would like to assess and mitigate GHG emissions from the perspective of ice cream supply chain. Unilever has already used several approaches to assess the GHG emissions associated with individual ice cream products. Ben & Jerry’s Europe produces a variety of ice cream flavours for sale and they first started to assess and manage their total carbon footprint in 2003 (Sim, Garcia-Suarez, Marshall, & Mauser, 2009). The carbon footprint of Ben & Jerry’s is around 2 kg CO\textsubscript{2} equivalent per litre (Wieriks, Vosbeek, Ginsel, & Hofman, 2007). One available approach is based on energy measurements in ice cream factories; three others used life cycle assessment focused on certain products and flavours, e.g. vanilla or chocolate flavoured ice cream (Shonfield, 2004; Wieriks, Vosbeek, Ginsel, & Hofman, 2007) or particular life cycle stages, e.g. dairy farming and milk production (Van Calker, Beldman, & Mauser, 2005); another one is based on the mass balance approach for total production of Ben & Jerry’s ice cream in Europe.

There are data and information gaps between those available approaches and China’s conditions. Within the available studies, data and assumptions were based on the local production conditions in Europe. It would be wrong to evaluate GHG emissions of ice cream with them in China, in that many aspects are of difference from European business. From this perspective of supply chain management, it is essential to know where hotspots are for mitigating GHG emissions of ice cream in China. It is therefore interesting to do one research to gain an insight of the GHG emissions of ice cream in China.

This report firstly described the present ice cream market and production systems in China. Next to this methods and data used for the study were explained in detail. GHG hotspots and carbon footprint of ice cream in China were shown through scenario analyses. Consequently options for Unilever to reduce GHG emissions were given from the perspective of the ice cream supply chain.
2. RESEARCH PLAN

2.1 Research aim
The research aims to find hotspots of GHG emissions and pragmatic solutions of the ice cream chain in China.

2.2 Research questions

Main research question:
What’s the carbon footprint of one litre ice cream in China?

Sub-questions:
- What does the dairy farming system look like in China?
- What does the milking system look like in China?
- What does the supply chain of ice cream in China look like?
- I. Do the sources of dairy materials affect the GHG emissions?
  - What are the volumes of dairy materials sourced for ice cream production in China, and where?
- II. How does the production process affect the GHG emissions?
  - What is the production volume?
  - How much energy is needed to produce one unit of ice cream?
- III. How do the distribution and storage patterns affect the GHG emissions?
  - What are the current distribution and storage patterns?
  - How much energy is needed for storing and transporting ice cream?

2.3 Boundaries
The research will focus on the ice cream production of Unilever in China. GHG emissions from the whole ice cream chain will be considered, including sources of materials, ice cream production and distribution. Only milk powders will be considered because they are the key ingredients for ice cream production. Fresh milk as the raw materials for producing milk powders is sourced from different dairy farming systems. The production volume of ice cream is based on that in 2008 and the sourced volumes of ingredients as well.

Carbon dioxide (CO$_2$), methane (CH$_4$) and nitrous oxide (N$_2$O) are the major GHGs and the subject of the Kyoto Protocol (United Nations, 1998). Although the chlorofluorocarbons (CFCs) are GHGs, they are regulated by the Montreal Protocol (United Nations Environment Programme, 2000), which was motivated by CFCs' contribution to ozone depletion rather than by their contribution to global warming. Carbon dioxide, methane and nitrous oxide are considered along the entire chain.

2.4 Methods and data
Literature study is essential within this project. All of data, e.g. emission factors and energy use, will be collected from available articles and database.

Investigations into the relevant ice cream producers in China will be used to obtain the current practical data in China, e.g. sources and volumes of raw materials and electricity use.

Mass balance approach and scenario analyses on how the different dairy farming systems, production quantity, and distribution and storage patterns affect the GHG emissions of ice cream will be made to gain insight into the GHG emissions.
3. PRESENT MARKET, ICE CREAM PRODUCTION SYSTEM IN CHINA

3.1 Present ice cream market in China

There are many brands of ice cream being sold on the market in China. Statistics show that the production and sales volume of enterprises involved in ice cream production with a certain market scale in China reached 2.05 million tons in 2007, gaining the turnover of RMB 15.5 billion yuan (equalling to 1.6 billion Euros) (Zhang, 2008). According to the China Marketing and Media Study' database, the top five brands in terms of market share - Yili, Wall’s (Unilever), Mengniu, Nestle and Meadow Gold - hold a 57% stake of the Chinese market, within which Wall’s, Nestle and Meadow Gold own 30% and the two domestic brands have the other 27% of the market (as cited in China Daily, 2004). Dairy Queen and Haagen-Dazs are two famous foreign brands in China as well. The growth of ice-cream parlours, pioneered by Haagen-Dazs in China, appearing in all major cities is evidence of a growing popularity with luxury brands (FHC China, 2008).

However, the foreign brands were unable to beat the major domestic brands like Mengniu and Yili in the low-price range as they had less powerful distribution networks, failed to cater to local people's tastes and came up against hikes in the prices of raw materials. Generally ice cream in China is categorized into three items in terms of its price. Low-end ice creams are priced below one yuan (around 0.1 Euros), with mid-priced ice creams at around two yuan and high-end products priced above two yuan. About 70-80% of the sales in 2006 came from products priced in the 1-1.5 yuan range (Xinhua, 2007).

3.2 Present ice cream production of Unilever in China

Unilever owns four ice cream factories in China, locating in Beijing, Taicang, Wuhan and Hong Kong respectively (Figure 1). The aggregate ice cream production volume in 2008 is 80.5 million litres. Beijing’s factory shared 31%, Taicang shared 54%, Wuhan and Hong Kong contributed 7% individually. This production quantity was twice output in 2006 (S. de Lint, personal communication, May 7, 2009). Nonetheless, the total production volume is still small compared to its large market.
Figure 1 Location of Unilever ice cream factories in China and some famous dairy products manufacturers, Nestle in Heilongjiang, Sanyuan in Beijing, Bright in Shanghai and Mengniu and Yili in Inner Mongolia. Area related milk production and dairy belt is shown with the thick line indicating 70% of the recent growth in dairy’s herd (Moria, 2008).

3.3 System descriptions of ice cream

The food supply chain is composed of a wide variety of products and companies which operate in different markets and sell a variety of food products (Bukeviciute, Dierx, & Ilzkovitz, 2009). Its activities transform natural resources, raw materials and components into a finished product that is delivered to the end customers. According to this definition, the whole supply chain of ice cream can be divided into such three general stages as sourcing ingredients or raw materials, manufacturing and distributing. Milk or milk powders, e.g. skimmed milk powder, whole milk powder and whey powder, are key ingredients for ice cream production. Fresh milk is produced from dairy cows of different dairy farming systems. Some other ingredients such as flavours, chocolate and sugar are added at the ice cream factories. After the manufacturing process in factories, ice cream is distributed to different places and completes the process from cows on farms to the retailers. Figure 2 shows an overview of the supply chain of ice cream. In terms of this simplified chain subsystems included in the study will be described as follows.
3.3.1 Dairy farming systems

Fresh milk is the primary material for dairy products production. It can be produced from different dairy farming systems. Sevenster and de Jong (2008), Moria (2008) and some other studies (Vergé, Dyer, Desjardins, & Worth, 2007; Basset-Mens, Ledgard, & Carran, 2005; Basset-Mens, Ledgard, & Boyes, 2009) have synthesized many studies on life cycle assessment of milk production from different farming systems in different countries. Unfortunately, there is no such information over milk production in China.

Some researchers (Ma, Rae, Huang, & Rozelle, 2007; Li, 2008; Wang, 2006) classified dairy farming systems in China into such three items as pastoral grazing farms, small-scale dairy farms (or smallholder dairy farms) and large-scale dairy farms (or suburban dairy farms). Pastoral grazing farms account for less than 10% of dairy farms and supply less than 10% of milk (Wang, 2006).

Therefore, this research will take into account small-scale and large-scale dairy farms. There are three reasons: 1) small-scale dairy farms account for more than 80% of dairy farms and supply more than 70% of milk in China (Chen, Hu, & Song, 2009; Li, 2008; Wang, 2006); 2) large-scale dairy farms take up a small fraction of dairy farms (Chen, Hu, & Song, 2009), but provide 20% of milk (Wang, 2006); 3) intensive dairy farming is a trend in China in the future to meet the increasing demands of milk (Moria, 2008). More concentrated dairy farms are being formed near suburban areas (Ma, Rae, Huang, & Rozelle, 2007). It can better control the diseases of cows and the quality of milk. These two dairy farming systems can be simplified as shown in Figure 3.
Small-scale dairy farming system

Small-scale dairy farms contribute a huge share of the milk production in China. They are in a scale of 1 to 5 dairy cows. There are 340,000 households that own and operate dairy farms with an average size of only 4.2 cows per household and most of them have other income sources (Främling, 2006). Totally 1.5 million small-scale dairy farms are in China accounting for more than 85% of dairy farms (Wang, 2006). These farms are mainly located in the agricultural areas in northern China and cows are kept mostly in backyard sheds. Dairy cows are fed with grains and crop residues which are produced from cow owners’ crop fields. Around 2500 kg milk per cow is the average annual yield on the household dairy farm.

A Village Milking Centre (VMC) plays a role in collecting and transporting fresh milk to milk products processors in this system. A VMC consists of milking machines, cleaning units, hygiene packages, bulk milk coolers and milk analysers. A VMC serves for 300 to 1000 dairy cows fed by 100 to 300 households in a village within a range of 1 to 2 kilometres (Främling, 2006). Local farmers bring their cows to the VMC where the cow is milked; milk is collected and efficiently cooled to ensure milk quality. VMCs are becoming more and more important in China because of the increasing consumption of dairy products and growing demands for quality milk (Främling, 2006).

Large-scale dairy farming system

Large-scale dairy farms usually refer to the suburban dairy farms in China. The suburban is China-specific indicating the rural areas in city districts and counties that surround China’s large cities. Suburban areas are under the administrative jurisdiction of the city government (Ma, Rae, Huang, & Rozelle, 2007). Large-scale dairy farms tend to be somewhat larger, more intensive and more market-oriented than small-scale ones. It is commonly assumed that the location of milk production in China is moving to suburban areas, closer to the major markets and the urban-based milk processing enterprises.

Additionally these large-scale dairy farms are state-owned (Li, 2008). Since there are no data that report total cow numbers or dairy output systematically for the entire country, information from the literature was relied on to collect the numbers and the sizes of these large-scale dairy farms. Roughly 2000 state-owned dairy farms exist in China with an average herd size of 120 cows and average an-
nual yield of around 6000 kg per cow (Främling, 2006). In fact some extremely large dairy farms also exist, where the numbers of dairy cows run in the thousands.

Generally large-scale dairy farms have their own milking centres on farms. After collecting the fresh milk, they transport the milk directly to the local milk products processors nearby.

3.3.2 Raw materials for ice cream production

Ice cream manufacturers of Unilever in China use various kinds of milk powders as raw materials (W. Wu personal communication, May 19, 2009). At the same time factories also purchase other ingredients such as sugar, chocolate and yolk, but they strongly depend on the tastes of the ice cream. To keep in line with the main goal of this research, only milk powders are taken into account.

Skimmed milk powder, whey powder and whole milk powder are three main materials for ice cream production of Unilever in China. Skimmed and whole milk powders have different fat content. This difference results from the different fat content of skim milk and whole milk as raw materials for producing milk powders (Ramirez, Patel, & Blok, 2006). However, the protein, calcium, and riboflavin content are rather similar. In this research all of them are combined together as milk powders.

Milk to milk powders conversion

Milk powder is produced by evaporating the water from the milk using heat. Its production quantity depends on the solids contents of fresh milk. Fresh milk generally contains about 13 % solids (Walstra, Wouters & Geurts, 2006). The milk is homogenised, heat treated and pre-concentrated before drying. There are a number of ways to produce dried milk powder including spray drying and roller drying.

Whey powder can be obtained by dried whey. Whey is a main by-product from the cheese production process. It contains approximately 50% of the lactose of fresh milk, as well as proteins, vitamins and minerals. Although whey contains valuable nutrients, it is only in recent years that new commercial processes are being developed for the manufacture of high quality whey products such as protein and vitamins.

3.3.3 Making ice cream in factories

The ice cream production process is an integrated process with manufacturing, packaging and storing. Various kinds of ingredients as milk powders and sugar are blended together in factories, and then through several different processes of pasteurization, homogenization, cooling, aging and freezing, ice cream is packaged and stored in freezing warehouses in plants. In China electricity use of ice cream in plants mainly includes two parts, one is for producing ice cream; the other is for storage. The electricity use of storage averagely shares 25% to 30% of total electricity use yearly (W. Wu, personal communication, Aug. 19, 2009). This study treated these two stages as ice cream in factories.

3.3.4 Distributing ice cream

Ice cream is assumed to be directly distributed from plants to retailers. In practical conditions individual business entrepreneurs also sell ice cream after purchasing from some intermediate traders or suppliers. This is still an important sale style in China.

Unilever can provide several types of freezer cabinets with retailers. Unilever has been working in close cooperation with Greenpeace on climate-friendly refrigerants in an alliance called Refrigerants Naturally! to promote HFC (hydro fluorocarbon)-free refrigeration technologies (Corporate Citizenship, 2008). Unilever has made good progress in Europe and extended the roll-out to China and US during 2008 to replace all the cabinets. By early 2009 Unilever had over 400000 hydrocarbon refrigerant cabinets in use which accounted for 20% of Unilever owned point-of-sale ice cream freezer cabinets worldwide (Corporate Citizenship, 2008). This research assumed that all the freezer cabinets are environmentally friendly. That means all the freezer cabinets use hydrocarbon as a refrigerant.

3.3.5 Transportation within the supply chain

Transportation plays an important role like nodes in connecting different stages in the ice cream chain. The following transporting activities are taken into account, including transporting fresh milk...
to milk products processors, transporting milk powders to ice cream factories and transporting ice cream to selling points.

The transfer of intermediate goods can be directly between firms involved in production or sale to consumers or, as is often the case, via specific wholesalers (Bučkevičiūte, Dierx, & Ilzkovitz, 2009). In practice, transfers in the ice cream chain are mixed with these patterns. Given the complexity, the transportation distance between different stages is longer than direct transfer from one stage to the next one. This study assumed that all the transportation activities occur directly between different stages.

### 3.3.6 Some omitted stages

In general, within the supply-chain-based analysis every step in the product’s life cycle is assessed. The steps involve the production of raw materials and transport to the production of the final product, the end-use and end of life scenarios (waste, recycling). Some stages have been omitted in the study due to the unavailability of data. They are indicated by dotted line in Figure 2 including:

1. Producing some other ingredients or additives such as yolk, sugar and chocolate. Since one of the main goals of this research is to see how different dairy farming systems affect GHG emissions of ice cream. However, producing such kinds of ingredients also implies huge GHG emissions in their life cycles. It should be investigated based on available literature in the future.

2. Consumers purchase ice cream from retailers and transport them to houses, and store them in domestic refrigerators for some time. This stage is full of uncertainties and easily affected by consumers’ behaviours. Behaviours are difficult to control and evaluate. For instance, consumers can buy ice cream daily from selling points instead of storing them at home. After purchasing ice cream from supermarkets, they can carry them to houses by various kinds of transportations such as by foot, by public transportation, by bike or by their own cars etc. In fact in summer most people are accustomed to buying ice cream at selling points and eating them immediately. Thus this research will omit this stage which is closely related with psychology and consumption customs.

3. Disposal of residues. Previous study about Ben & Jerry’s ice cream show that disposal of residues results in minor global warming (Shonfield, 2004). Moreover there is no relevant emission data over disposing of residues in China.
4. METHODOLOGIES AND DATA

4.1 Methodologies

A carbon footprint is the total set of GHG emissions caused directly and indirectly by an individual product expressed as CO$_2$ equivalent (Carbon Trust, 2009). Carbon footprint is a more recent term for GWP and refers to the total GHG emissions associated with a product or service. Emissions of different individual GHG are converted into GWP and expressed in the common unit of CO$_2$-equivalents. This study will use this concept to express the climate impacts caused by the ice cream chain. The unit is of kg or g CO$_2$ equivalent per litre ice cream.

The GWP for each GHG allows comparison of impacts for combined emissions from different stages. Each GWP is the contribution that a gas makes to the greenhouse effect, and is indexed to CO$_2$ according to its capacity to absorb radiation and its residence time in the atmosphere. The commonly used GWP means that, as GHG, N$_2$O is 298 times more powerful than CO$_2$ on a mass basis and methane is 25 times more powerful (IPCC, 2006).

Mass balance approach was used in calculating the ice cream’s carbon footprint in each stage. Seven stages, including dairy farming, transporting fresh milk, making milk powder and their transportation, manufacturing, distributing and storing ice cream at selling points, were taken into account. GHG emissions from these stages are indirect except emissions from manufacturing process in factories. Practical data such as production volume, energy use and volumes of sourcing ingredients were collected from Unilever’s ice cream factories in China. Mass balance among fresh milk, milk powder and ice cream can be obtained through the yearly production volume and its consequent milk powder consumption. Thus based on the mass balance and energy use per litre ice cream in each stage, the carbon footprint in each stage can be obtained through multiplication with emission factors of each stage. Equations 1 to 7 illustrate the calculation of carbon footprint of ice cream in the mentioned seven stages.

The carbon footprint of ice cream resulted from on-farm dairy farming can be calculated by Equation 1.

\[
CF_{farm} = M \times EF_{farm} \quad \text{Equation 1}
\]

where \( CF_{farm} \) indicates the on-farm carbon footprint resulting from producing milk for ice cream production (g CO$_2$ eq./litre ice cream); \( M \) is the fresh milk used to produce one litre ice cream (kg milk/litre ice cream), which is converted into milk powder in milk products processors; \( EF_{milk} \) is the emission factor of producing one unit of fresh milk (g CO$_2$ eq./kg milk).

Equation 2 shows the carbon footprint of ice cream resulting from transporting fresh milk to milk products processors.

\[
CF_{transp.milk} = M \times D_m \times EF_{transp.} \quad \text{Equation 2}
\]

where \( CF_{transp.milk} \) indicates the carbon footprint of ice cream resulting from transporting milk to milk products processors (g CO$_2$ eq./litre ice cream); \( M \) is the fresh milk used to produce one litre ice cream (kg milk/litre ice cream); \( D_m \) is the average distance of fresh milk on the way to processors (km); \( EF_{transp.} \) is the emission factor of cooling lorry transportation (g CO$_2$ eq./kg.km).

The carbon footprint of ice cream resulted from manufacturing milk powders can be calculated by Equation 3.

\[
CF_{powder} = MP \times EF_{powder} \quad \text{Equation 3}
\]

where \( CF_{powder} \) indicates the carbon footprint of ice cream resulting from manufacturing milk powder used for ice cream (g CO$_2$ eq./litre ice cream); \( MP \) indicates the demand of milk powder used to produce one litre ice cream (kg milk powder/litre ice cream); \( EF_{powder} \) is the emission factor of milk powder production (g CO$_2$ eq./kg milk powder).
Equation 4 is used to calculate the carbon footprint of ice cream related with transporting milk powders to ice cream factories.

\[ CF_{\text{transp.powder}} = MP \times D_{\text{mp}} \times EF_{\text{transp}} \]  

where \( CF_{\text{transp.powder}} \) indicates the carbon footprint of ice cream resulting from transporting milk powders from processors to ice cream factories (\( \text{g CO}_2 \text{ eq./litre ice cream} \)); \( MP \) indicate the demand of milk powder used to produce one litre ice cream (kg milk powder/litre ice cream); \( D_{\text{mp}} \) is the average distance from milk products processors to ice cream factories (km); \( EF_{\text{transp.}} \) is the emission factor of general lorry transportation (\( \text{g CO}_2 \text{ eq./kg.km} \)).

The climate impacts resulting from electricity use in factories can be obtained through Equation 5.

\[ CF_{\text{factory}} = Ele_{\text{factory}} \times EF_{\text{ele.}} \]  

where \( CF_{\text{factory}} \) indicates the carbon footprint of processing ice cream in the factory (\( \text{g CO}_2 \text{ eq./litre ice cream} \)); \( Ele_{\text{factory}} \) is the electricity use for manufacturing ice cream in the factory (kWh/litre ice cream); \( EF_{\text{ele.}} \) is the emission factor of generating electricity (\( \text{g CO}_2 \text{ eq./kWh} \)).

Equation 6 shows the carbon footprint resulted from distributing ice cream to selling sites or market served by one factory.

\[ CF_{\text{distribution}} = \rho \times D_{\text{distribution}} \times EF_{\text{transp.}} \]  

where \( CF_{\text{distribution}} \) indicates the carbon footprint of ice cream resulting from distributing ice cream from factories to retailers for (\( \text{g CO}_2 \text{ eq./litre ice cream} \)); \( \rho \) is the density of ice cream (kg/litre ice cream); \( D_{\text{distribution}} \) is the average distance from ice cream factories to retailers (km).

The climate impacts resulting from storing ice cream in freezer cabinets at selling points can be calculated by Equation 7.

\[ CF_{\text{freezer}} = Ele_{\text{freezer}} \times EF_{\text{ele.}} \]  

where \( CF_{\text{freezer}} \) indicates the carbon footprint of ice cream resulting from storing it at selling points in freezer cabinets (\( \text{g CO}_2 \text{ eq./litre ice cream} \)); \( Ele_{\text{freezer}} \) is the electricity use for storing ice cream at selling points (kWh/litre ice cream); \( EF_{\text{ele.}} \) is the emission factor of generating electricity (\( \text{g CO}_2 \text{ eq./kWh} \)).

Energy use is closely related with GHG emissions. Based on the mass balance of ice cream and energy use of producing fresh milk and milk powders or energy use of each stage, the energy use of one litre ice cream can be obtained. Through multiplying the population, the ice cream consumption per capita with the carbon footprint or energy use of ice cream, the (future) total GHG emissions and energy use can be figured out.

4.2 Data applied to scenario analyses

Mass balances among fresh milk, milk powder and ice cream can be diverse due to the flavour of ice cream. The flavour is relevant for the taste of local consumers. This study concerned the practical production in 2008 as a benchmark to calculate its mass balance. Totally 3480 tons milk powders were used to meet the production demands, including 2475 tons skimmed milk powder, 115 tons whole milk powder and 890 tons whey powder and Unilever produced approximately 80.5 million litres ice cream in China’s market in 2008 (W. Wu, personal communication, May 18, 2009). Therefore, general production of one litre ice cream needs about 43 g milk powders. It implies 338 g fresh milk for one litre ice cream based on the solids content of fresh milk around 13%.

The fresh milk needed to produce one litre ice cream in China is less than that in the Netherlands studied in a Life Cycle Assessment, 500 g fresh milk per litre ice cream (R. Benders, personal communication, Dec. 10, 2009). This difference resulted from the difference of taste between Chinese and Dutch and the short history of eating dairy products in China.
The density of ice cream differs for each product. In general, the ice cream density of Unilever is 500 g per litre (J. K. Vis, personal communication, Oct. 13, 2009). Ben & Jerry’s density is higher, 880 g per litre (Wieriks, Vosbeek, Ginsel, & Hofman, 2007). The difference lies firstly in the taste difference, indicating that Ben & Jerry’s uses more chocolate, cookies etc.; secondly Ben & Jerry’s lower overrun (the air whipped into the ice cream mix).

Dairy farming affects the climate change by emitting methane, nitrous oxide and to a lesser extent through emissions of carbon dioxide (Moria, 2008). Enteric fermentation and anaerobic decomposition of manure both contribute to methane production, but overall about 80% of on-farm methane emissions are from enteric fermentation (Vergé, Dyer, Desjardins, & Worth, 2007). Nitrous oxide is produced as a consequence of manure storage and application on fields, by means of nitrogen transformation in manure and in the soil. Moreover, soil cultivation and nitrogen fertilizer utilization stimulates naturally occurring bacteria to produce more nitrous oxide (IPCC, 2006). The production of energy used for manufacturing feed concentrates and for forage production and housing systems determines carbon dioxide emissions.

Due to unavailability of Chinese emission factors of dairy farms, emission factors of milk production in available countries substituted for China’s dairy farming. Small-scale dairy farms were represented by New Zealand’s conventional system and large-scale ones were represented by Dutch conventional system (Table 1). New Zealand’s dairy farming is largely dependent on pastoral feed source which has a low digestibility and most of the excreta are directly applied onto pasture (Basset-Mens, Ledgard, & Boyes, 2009). This production style is similar to small-scale dairy farms in China, which feed a lot of crops residues to cows and apply manures onto the crops fields. Dutch milk production systems are characterized by high intensity and yields. Cow genetics, feeding strategies and the introduction of the milking machines and robots all contribute to increasing the yields per cow. A large amount of feed production and utilization is characterized by a high fertilizer and concentrates use (Moria, 2008). This production pattern is the same as large-scale dairy farms and will be a trend in the future due to the increasing consumption of milk products in China.

Table 1 GWP and emission factors of conventional and organic dairy farming systems in different countries.

<table>
<thead>
<tr>
<th>Farm type</th>
<th>GWP (g CO₂ eq./kg milk)</th>
<th>CH₄ (g CO₂ eq./kg milk)</th>
<th>N₂O (g CO₂ eq./kg milk)</th>
<th>CO₂ (g CO₂ eq./kg milk)</th>
<th>Yield (kg/cow/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Netherlands a,e</td>
<td>conventional 1484</td>
<td>567</td>
<td>511</td>
<td>406</td>
<td>7991</td>
</tr>
<tr>
<td></td>
<td>organic 1600</td>
<td>768</td>
<td>577</td>
<td>255</td>
<td>6138</td>
</tr>
<tr>
<td>Canada b</td>
<td>conventional 1116</td>
<td>673</td>
<td>300</td>
<td>143</td>
<td>9400</td>
</tr>
<tr>
<td>New Zealand c,d</td>
<td>conventional 787</td>
<td>487</td>
<td>235</td>
<td>65</td>
<td>4120</td>
</tr>
<tr>
<td></td>
<td>organic 1018</td>
<td>573</td>
<td>325</td>
<td>120</td>
<td>7690</td>
</tr>
<tr>
<td>Sweden a,e</td>
<td>conventional 965</td>
<td>493</td>
<td>304</td>
<td>168</td>
<td>9240</td>
</tr>
<tr>
<td></td>
<td>organic 1018</td>
<td>573</td>
<td>325</td>
<td>120</td>
<td>7690</td>
</tr>
<tr>
<td>Germany a,e</td>
<td>conventional 1418</td>
<td>840</td>
<td>401</td>
<td>177</td>
<td>6758</td>
</tr>
<tr>
<td></td>
<td>organic 1451</td>
<td>1011</td>
<td>352</td>
<td>88</td>
<td>5275</td>
</tr>
</tbody>
</table>


In recent years conventional livestock farming has been impressively successful at increasing the performance of farm animals and decreasing the production costs. At the same time, production-intensification has pushed the issues of environmentally friendly production, animal health and welfare into the background, especially because these are cost- and labour-intensive. Organic farming has set itself the goal of establishing environmentally friendly production, sustaining animals in good health, realizing high animal welfare standards, and producing products of high quality (Sundrum, 2001). Organic farming can also satisfy the demands of biodiversity, species preservation, protection of nature, of landscape, of groundwater etc. (Philips, & Sorensen, 1993). It can meet the demands of increasing number of consumers who are critical of conventional production methods. Therefore, it is
interesting to gain an insight into whether organic farming system is climate-friendly for supplying fresh milk to manufacture ice cream. There is no available data over these two dairy farming systems in China, but some published studies (Table 1) have done relevant Life Cycle Assessment in several countries.

Milk powder manufacturing process has the highest direct energy demand per ton of finished products in the entire dairy sector (Wang, 2008). This process needs not only electricity but also fuels combustion or heat. There is no available data relevant to energy use for producing milk powders in China. The study used Dutch data in 2001 instead of Chinese data (as cited in Wang, 2008, p. 270). Totally about 10.5 MJ of energy, including electricity and specific fuels, is needed to produce one kilogram milk powder. Energy from fuel combustion accounts for 90% and other energy is electricity. To generate one kilowatt hour (1kWh) electricity gives rise to the GWP of 845 g CO$_2$ equivalent in China (EIA, 2007). The specific fuel indicated natural gas in the study, which has lower emission factors than electricity generation. Its GWP is around 56.3 kg CO$_2$ equivalent per GJ (IPCC, 2006, Table 3). The GWP and emission factors of manufacturing milk powders can be obtained through the combination of electricity use and natural gas use for one kilogram milk powder with the emission factors of electricity generation and natural gas combustion. To produce one kilogram milk powder implies the GWP of 787.7 g CO$_2$ equivalent.

Table 3 Global warming potential of electricity generation in China, natural gas combustion and milk powder production.

<table>
<thead>
<tr>
<th></th>
<th>CO$_2$</th>
<th>CH$_4$</th>
<th>N$_2$O</th>
<th>GWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity generation</td>
<td>839</td>
<td>0.37</td>
<td>5.5</td>
<td>844.9</td>
</tr>
<tr>
<td>(g CO$_2$ e./kWh)$^1$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural gas combustion</td>
<td>56000</td>
<td>34.5</td>
<td>298</td>
<td>56333</td>
</tr>
<tr>
<td>(g CO$_2$ e./GJ)$^2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk powder$^3$</td>
<td>782.8</td>
<td>0.4</td>
<td>4.5</td>
<td>787.7</td>
</tr>
<tr>
<td>(g CO$_2$ e./kg milk powder)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: 1. EIA (2007); 2. IPCC (2006); 3. own calculation based on energy use of milk powder production (Wang, 2008) and emission factors of electricity generation and natural gas combustion.

The direct carbon footprint of ice cream is in the ice cream factories. It mainly results from the electricity use within the manufacturing process. Electricity use per unit of ice cream in factories differs for each factory yearly. The amount of electricity consumption can be directly gathered from ice cream factories. In 2008, for instance, the average electricity use is 436.3 kWh/1000 litres, while in 2006 it is 519k Wh/1000 litres (De Lint, personal communication, May 7, 2009), although the total production volume in 2006 is only half of that in 2008. While in Europe it is around 170 kWh/1000 litres (B. Diprose personal communication, Oct. 16, 2009). This large difference may be caused by many factors, such as electricity use efficiency and production quantity. Due to the time limit and the scope of this research, no concrete investigation was made to explain the electricity use difference between China and Europe. This research considered the electricity use per unit of ice cream as a constant in China in the future.

Table 2 Emission factors of different kinds of transportation.

<table>
<thead>
<tr>
<th></th>
<th>CO$_2$ (g CO$_2$ eq./t.km)</th>
<th>CH$_4$ (g CO$_2$ eq./t.km)</th>
<th>N$_2$O (g CO$_2$ eq./t.km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lorry</td>
<td>206</td>
<td>8.7</td>
<td>6.3</td>
</tr>
<tr>
<td>Cooling lorry</td>
<td>230.7</td>
<td>9.8</td>
<td>7.0</td>
</tr>
<tr>
<td>Ship (55000 tons)</td>
<td>8.58</td>
<td>0.29</td>
<td>0.014</td>
</tr>
</tbody>
</table>

Transportation connecting each stage implies GHG emissions through fossil fuels combustion. There are several important kinds of transportation in China like railway, water way, highway and pipeline. The method of transporting fresh milk to processors is based on highway transportation with cooling lorries. Their emission factors are higher than those of general lorries because more energy is used to keep the low temperature for food (Kok, Benders, & Moll, 2001). Cooling lorry would cause 248 g CO₂ equivalent to transport one ton freight one kilometre, whereas the general lorry is around 221 g CO₂ equivalent per ton per kilometre (Table 2). Cooling lorries are also used to distribute ice cream from factories to selling points. For transporting milk powders it is possible to use other methods available in normal temperature. This study assumed that they are transported by highway with general lorries when purchasing milk powders from domestic milk products processors and by ship when importing milk powders from other countries.

Here the emission factors of different transportation patterns were represented with data from the Netherlands due to the unavailability of relevant Chinese data. As the practical transportation conditions, technologies by trucks or ships and fossil fuels used in China are different from the Netherlands, the emission factors of all kinds of transportation used here could be undervalued compared to practice in China. In China the energy use of road transportation and marine transportation is 4.1 MJ/t.km (Asia Pacific Energy Research Centre, 2004) and 0.4 MJ/t.km (Michaelowa & Krause, 2000) respectively, whereas in the Netherlands each of them is much lower, 2.3 MJ/t.km and 0.13 MJ/t.km respectively (R. Benders, personal communication, Dec. 10, 2009). These variations can be one proof leading to undervalue emission factors of transportation.

Distance is the dominant element affecting GHG emissions on transporting given amounts of cargoes as the emission factors of one transportation method are relatively determined. Small-scale dairy farms are scattered farther from milk products processors than large-scale ones. This difference is the cause of small-scale farms locating in villages and large-scale ones in suburban areas, while milk products processors locate in suburban areas as well. The distance between processors and milking centres of small-scale system was assumed to be in an average range of 200 km, and the large-scale system has an average distance of 100 km.

Unilever has many options to purchase milk powders in China. Nearly 1600 dairy products companies locate in China and most of them are in the northern China (Li, 2008; Chen, Hu, & Song, 2009, Appendix 1). The location of some processors is shown in Figure 1. Unilever can purchase powders from either local companies nearby, except Hong Kong, or processors far away. This activity can be affected by both market conditions such as price, quality and processors’ production capacity. This study classified the distance into 100 km, 500 km, 1000 km and 2000 km, based on the rough distances between processors and factories (Appendix 2 or Figure 1). For instance, Taicang factory can purchase milk powder from Bright Dairy Company, located in Shanghai, with a distance of about 45 km. However, if it would buy milk powder from Mengniu or Yili, two large dairy companies located in Inner Mongolia, the distance would be around 1340 km, and if from Shuangcheng Nestle in northeast China, the distance would be over 2200 km.

Moreover, ice cream factories can purchase raw materials from the world market. After Melamine Issue 2008 in China (Appendix 3) Unilever has been purchasing milk powders from the world market, e.g. New Zealand, Canada, the Netherlands etc. (W. Wu, personal communication, May 18, 2009). The study therefore also evaluated the GHG emissions from shipping milk powders to the harbours near ice cream factories and then transporting to factories by trucks. The following three areas were concerned: Oceania, North America and Europe. The marine distance can be classified into three categories: 10 000 km (indicating import from Oceania, including New Zealand and Australia), 15 000 km (indicating from North America, including USA and Canada) and 20 000 km (indicating from Europe, including the Netherlands, Germany and Belgium etc.), based on from one large international harbour in these areas to one harbour near ice cream factories (Appendix 2).

Distributing ice cream to retailers can result in GHG emissions through fossil fuel combustion in transportation. Retailers are scattered around ice cream factories in a range. The distance between ice cream factories and points of manufacturing to market served is assumed based on the different scales
of market. The service range of one ice cream plant is assumed to be in a minimum range of 200 km (local market), 1000 km (regional market) and maximally in 2000 km (national market).

Unilever can supply several kinds of freezer cabinets to retailers. They are different from each other at different practical operating conditions. Standard laboratory tests had been done by Unilever’s experts, but the results on field can be dramatically worse (F. Roberti, personal communication, June 18, 2009). Electricity use resulting from storing ice cream can be affected by the storing load. Higher load generally means lower electricity use per unit. In addition, some other factors such as the frequency of opening and closing cabinets can also result in variations over electricity use.

Through communication with Unilever’s experts, electricity use of several types of freezer cabinets with volumes of 200 litres was known. A Closed Top cabinet (horizontal insulated lids) requires at least 1 kWh per day, a Visi Top (horizontal glass lids) requires at least 2 kWh per day, an Angle Top (inclined glass lids) 3 kWh per day, and a Vertical Display (vertical glass door) from 8 to 17 kWh per day (F. Roberti, personal communication, May 12, 2009). We only took into account the type of the Vertical Display as an extreme representative and assumed its electricity use of 12.5 kWh per day in average. The load of freezer cabinets would be assumed in a middle load (60%) and high load (80%) respectively. Furthermore, ice cream would be stored in freezer cabinets for seven days before being sold. Table 4 shows the energy use of each stage concerned in the ice cream chain. Data were directly extracted from available literature except the electricity use of manufacturing and storing ice cream. Energy use in the study indicated direct energy use in the ice cream chain. Primary energy use mainly means fossil fuels for transportation and for making milk powders and secondary energy use is in on-farm production, making milk powders, manufacturing and storing ice cream.

Table 4 Energy use of each stage included in the ice cream supply chain.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Direct energy use</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk production¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>small-scale</td>
<td>1.4</td>
<td>MJ/kg milk</td>
</tr>
<tr>
<td>large-scale</td>
<td>5</td>
<td>MJ/kg milk</td>
</tr>
<tr>
<td>Milk powder production²</td>
<td>10.5</td>
<td>MJ/kg milk powder</td>
</tr>
<tr>
<td>Ice cream production³</td>
<td>1.6</td>
<td>MJ/litre ice cream</td>
</tr>
<tr>
<td>Freezer storing³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>middle-load</td>
<td>2.6</td>
<td>MJ/litre ice cream</td>
</tr>
<tr>
<td>high-load</td>
<td>2</td>
<td>MJ/litre ice cream</td>
</tr>
<tr>
<td>Transportation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>road⁴</td>
<td>4.1</td>
<td>MJ/ton.km</td>
</tr>
<tr>
<td>marine⁵</td>
<td>0.4</td>
<td>MJ/ton.km</td>
</tr>
</tbody>
</table>

5. INTEGRATED RESULTS

The carbon footprint and energy use of ice cream were calculated by applying the above mentioned data to Equations 1 to 7. Table 5 shows an overview of carbon footprint and energy use of one litre ice cream in each stage. There are many different combinations in terms of different scenario choices. For example, milk powders for ice cream production are produced from small-scale dairy farms and they are purchased from processors in a distance of 2000 km; ice cream is distributed to local market and stored at freezer cabinets with a middle load (60%). The carbon footprint of one litre ice cream is 1.57 kg CO$_2$ equivalent and the energy use is 9.93 MJ/litre ice cream. The smaller carbon footprint corresponds to small-scale dairy farms, shorter transportation distances between each stage and higher storage load at selling points. Conversely, the larger carbon footprint is in accordance with large-scale dairy farms, longer transportation distances and lower storage load (Table 5). The energy use of ice cream varies accordingly.

Table 5 Carbon footprint and energy use of one litre ice cream in each stage.

However, shipping milk powders from Oceania, North America or Europe may result in smaller climate impacts than transporting milk powders from domestic processors, even though the shipping distance is far longer. This is not compatible with the proportionally increasing climate impacts with the rising transportation distances inland. Importing milk powders from Oceania, for instance, could lead to 3.8 g CO$_2$ equivalent per litre ice cream if the road transportation inland was not considered. It is comparable to transport milk powders from a domestic processor in a distance of 100-500km. Even though the road transportation was concerned, importing milk powders from Oceania could be comparable with transporting milk powders from domestic processors in a range of 1000 km to 2000 km. This is because shipping of given amounts of powders over a given distance emits fewer GHG emissions than road transportation by trucks (Table 2). Shipping milk powders from North America and Europe is also available and the climate impacts caused by marine transportation could also be com-
parable with transporting milk powders from domestic processors in a range of 1000 km to 2000 km. From the aspect of energy use, shipping given amount of cargoes to a given distance through road in China needs almost ten times energy than marine transportation (Table 4). This large difference also makes importing raw materials through marine transportation competitive with domestic road transportation.

Integrated results of carbon footprint and energy use of ice cream in the following analyses were based on extreme scenarios results presented in Table 5. The Minimum scenario is described as: Milk powders for ice cream production are produced from small-scale dairy farms and they are purchased from processors in a range of 100 km. Ice cream is distributed to the market in the distance of 200 km and stored at freezer cabinets with a high load (80%). The Maximum one is as follows: Milk powders for ice cream production are produced from large-scale dairy farms and they are purchased from processors in a range of 2000 km; ice cream is distributed to the market in a range of 2000 km and stored at freezer cabinets with a middle load (60%). Within these two extreme scenarios making milk powder and manufacturing ice cream are both under present conditions. Milk powders in these two scenarios are assumed to be purchased inside China.

5.1 Carbon footprint of ice cream

![Integrated carbon footprint of ice cream](image)

Figure 4 Minimum and maximum carbon footprint of ice cream. See scenario descriptions in the second paragraph in Page 24.

Production of one litre ice cream resulted in a carbon footprint of 1.2 kg to 1.8 kg CO$_2$ equivalent (Figure 4). It is lower than the carbon footprint of Ben & Jerry’s, 2 kg CO$_2$ equivalent per litre. This difference resulted from Ben & Jerry’s project concerned the entire life cycle of ice cream, including sugar production, packaging stuffs, wastes treatment etc. (Wieriks, Vosbeek, Ginsel & Hofman, 2007), which were omitted in the study.

On-farm dairy emissions, ice cream production in plants and storing ice cream at the selling points are three main contributing stages. The contribution of these three stages in the minimum scenario is around 94%, of which 23% originated from on-farm emissions, and 31% originated from processing in the ice cream factory and 40% originated from electricity consumption at the selling points.

However, in the Ben & Jerry’s results the stage of manufacturing ice cream in factories only contributed not more than 2% of the carbon footprint (Sim, Garcia-Suarez, Marshall, & Mauser, 2009). This large variation was due to two reasons. Firstly, factories in China store ice cream for some period until the freezing warehouses are full. About 25% to 30% of electricity is used for storing ice cream (W. Wu, personal communication, Aug. 19, 2009). In Europe ice cream will be stored in an independent freezing centre for some time. This different storing pattern leads to the electricity demand of 1000 litres ice cream in China 2.5 times to UK and Germany. Secondly, factories in Europe can purchase electricity with much lower GHG emissions. China largely depends on conventional thermal from combusting coal to generate electricity (82%), whereas in Germany and UK nuclear power and renewable energy account for 36% and 23% respectively in their energy mixes (EIA, 2007). In the
Netherlands 87% of electricity is generated by conventional methods, but the main energy source is natural gas with lower emission factors. Moreover, the renewable energy also accounts for 10% of Dutch energy mix (EIA, 2007). The difference of energy mix between China and Europe is also one key reason why storage at selling points can result in a much larger contribution to the ice cream carbon footprint.

Distribution of ice cream could also cause a lot more GHG emissions due to transport to a farther market served in the maximum scenario (Figure 4, right), of which distributing ice cream contributed 14% whereas in the minimum scenario only 2%.

Carbon dioxide is the major GHG within the supply chain of ice cream. Its contribution to the carbon footprint is around 80%, while methane and nitrous oxide only contribute 10% respectively (Figure 5). Carbon dioxide mostly originated from electricity use and fuels combustion in the ice cream plants and electricity consumption at the selling points, about 35% of which originated from processing in the ice cream plants and 45% originated from storage at the selling points (Figure 6). Small-scale dairy farms contributed less to the footprint than large-scale dairy farms, because large-scale dairy farms are more intensive in energy use, i.e. production and transportation of fertilizer-based concentrates. Electricity generation in China largely depends on conventional thermal generated by coal combustion. Therefore carbon dioxide emissions are high when using electricity for manufacturing process and storage.

![Figure 5](image)

**Figure 5** The contribution of each GHG to the carbon footprint of ice cream in extreme scenario results. See scenario descriptions in the second paragraph in Page 24.

![Figure 6](image)

**Figure 6** CO₂-induced carbon footprint in extreme results

Total: 920g CO₂ eq./litre ice cream  
Total: 1405g CO₂ eq./litre ice cream

![Figure 6](image)

**Figure 6** CO₂-induced carbon footprint of ice cream in every stage within the supply chain based on extreme scenario results. See scenario descriptions in the second paragraph in Page 24. Explanations of CH₄- and N₂O-induced carbon footprint are in the following text.
Production of fresh milk on dairy farms contributed nearly all of \( \text{CH}_4 \)-induced and \( \text{N}_2\text{O} \)-induced carbon footprint of the life cycle of ice cream. Both of them mostly originated from enteric fermentation of dairy cows, manure application on fields and production and transportation of concentrates. Meanwhile, electricity consumption in the stages of manufacturing in factories and storing at selling points could cause 5% of nitrous oxide because of burning large amounts of coal to generate power in China.

5.2 Energy use of ice cream

Production of one litre ice cream resulted in 5.8 MJ to 10.5 MJ energy use (Figure 7). Carbon footprint and energy use were highly connected since carbon footprint mainly resulted from the use of fossil energy. Electricity use and fossil fuels use for transportation are two main energy demands in the ice cream chain. Electricity use accounted for nearly 90% of all energy required in the minimum scenario. In the maximum scenario total electricity use accounted for about 55% of all energy required. This variation resulted from larger contribution of distributing ice cream in the maximum scenario, which accounted for almost 40% of energy use. However, its contribution to the carbon footprint did not correspond to its contribution of energy use. The difference resulted from the variations over primary and secondary energy use in the chain.

![Integrated energy use of ice cream](image)

Figure 7 Minimum and maximum energy use of ice cream. See scenario descriptions in the second paragraph in Page 24.

5.3 Conventional or organic dairy farming and consequent on-farm emissions of ice cream

Figure 8 shows the climate effects of one litre ice cream with using milk powders produced in different countries with conventional or organic dairy farms. The climate effect of organic ice cream and conventional ice cream are quite similar: the carbon footprint of organic ice cream is in average 4% higher than that of conventional ice cream. It is compatible with the difference of GHG emissions between the organic milk life cycle and the conventional milk life cycle (De Haas, Wettenrich, & Kipke, 2001; Thomassen, van Calker, Smits, Jepema, & de Boer, 2008; Sevenster, & De Jong 2008). Table 1 shows that organic farming emits less carbon dioxide than conventional farming due to its lower application of energy. Nevertheless, organic farming system emits more nitrous oxide and methane than conventional system, which have stronger GWP than carbon dioxide causing climate effect, due to its higher application of pastures and crops for feed supplement and manures on fields.
Conventional ice cream contributes more to mitigating its on-farm carbon footprint from milk production. Conventional ice cream of New Zealand has the smallest carbon footprint of 265.7 g CO$_2$ equivalent per litre, which is almost half of the Netherlands. This means, if only taking into account from cradle to farm-gate emissions of milk, sourcing milk from conventional dairy farms in New Zealand are much friendlier to the climate change. This is because Dutch systems are characterized by higher fertilizer on feed production and higher concentrate use, leading to importing larger amounts of concentrate ingredients and using more by-products from food industry, on one hand; on the other hand, New Zealand systems rely essentially on permanent mixed pastures grazed all year round which dramatically reducing fertilizer use and concentrate use on farms (Basset-Mens, Ledgard, & Carran, 2005).

5.4 Energy required for future ice cream consumption patterns in China

Through multiplying the total ice cream consumption with the energy use for one litre ice cream the future energy requirements for ice cream production can be calculated. Two different future consumption patterns were assumed: the expected Chinese pattern of 6 litres per capita per year in 20 years (China Daily, 2004), and the western consumption pattern of 20 litres per capita per year (University of Guelph, 2009). The Chinese population is assumed to be 1.4 billion in the future. The minimum energy use of 5.8 MJ per litre ice cream includes 90% of electricity use and 10% of fossil fuels; the maximum energy use of 10.5 MJ per litre ice cream includes 55% of electricity use and 45% of fossil fuels (see Figure 7). Figure 9 shows the total energy requirements for ice cream with different consumption patterns in 2020 in China.

Consuming more ice cream per capita in China implies less than 1% of total energy. The expected Chinese consumption level used 50 TJ (equalling to 14 billion kWh) electricity and the western level consumed 150 TJ (equalling to 52 billion kWh) electricity. According to National Bureau of Statistics of China (2008) in 2007 China totally consumed 3271 billion kWh electricity (production quantity was 3282 billion kWh). Hence the electricity used for ice cream production in 2020 would be marginal compared to the total electricity production.

Figure 9 also shows that fossil fuels required for transportation in the ice cream chain can be strongly reduced through shortening the transportation distances. The total amount of fossil fuels required in the minimum scenario is only one eighth of the maximum scenario. This is directly related to the far shorter transportation distances between each stage in the minimum scenario.
Figure 9 Energy required for different consumption levels of ice cream in China, using the extreme scenario results of energy use per litre ice cream.
6. OPTIONS AND DISCUSSIONS

A change to more ice cream consumption patterns implies more energy is required for its production and consequently more climate impacts resulting from its chain. With the economic development in China, a change to more luxurious diets also means far more energy requirements. Reducing the carbon footprint and energy use of ice cream can contribute to decrease the climate impacts and energy demands with the changing dietary patterns.

6.1 Mitigating on-farm GHG emissions

To reduce the climate impact of ice cream, decreasing the impact of milk would be one of the most efficient ways since almost all the emissions of methane and nitrous oxide resulted from dairy farms. Several studies suggest possible improvement options to reduce the ecological impact of milk (Cederberg & Mattsson, 2000; Thomassen, Dalgaard, Heijungs, & De Boer, 2008; Hospido, Moreira, Feijoo, 2003, as cited in Van Middelaar, 2009). Changing the feed composition to reduce on-farm methane emission and select regionally produced products or increase the self-supporting capacity of the farm to reduce the impact of production and transport of animal feed can contribute to a better ecological performance (Van Middelaar, 2009). However, some actors, e.g. farmers, feed manufacturers need to be persuaded when changing feed compositions. Feed manufacturers work on the basis of formulating least cost feeds. In principal the feed composition can be influenced by the price of the feed ingredients. In addition, farmers definitely choose the feed of the lowest price or the easiest accessible from the market. This option can be applied but it’s difficult to promise to achieve good results with extensive and genuine effects without cooperation with farmers and feed manufacturers etc.

Nonetheless, Unilever is able to mitigate the GHG emissions from dairy farms through investing effective manure management technologies cooperating with relevant parties, e.g. local governments and farmers. Nestle, for instance, has successful experiences upon manure storage to prevent contamination of ground water and emissions of methane and nitrous oxide. Nestlé Shuangcheng factory in China identified cheap, adequately-sized biogas digesters for manure storage. In cooperation with the local government, Nestlé agronomists trained farmers in correct handling and storage of farm manure and helped to install more than 1,500 small biogas plants (Nestle, 2009). These biogas generators not only help to prevent water pollution but also create energy for basic uses such as cooking and heating for farmers.

6.2 Changing energy mix

Carbon dioxide is the GHG that ice cream production can have a significant influence on (see Figure 5, the contribution of each GHG to Minimum and Maximum scenario). It mainly results from the production of energy from fossil energy sources. Energy is used in the whole chain in different forms depends on the demands of the process such as electricity use in feed production on farms, manufacturing ice cream and refrigeration milk and ice cream and fuels combustion. The main methods that can be used to mitigate these emissions are to reduce the energy consumption, in other words, to decrease the energy intensities in production and transporting, or to produce the required energy with a higher efficiency. The efficiency of generating required energy is uncontrollable by Unilever as it is determined by the energy suppliers in China.

Reducing the energy intensities needs tailor-made measures in terms of practical conditions in manufacturing, storing and transporting. For example, the combustion of different fossil energy can cause different emissions of carbon dioxide (Bertsch, 2007), so sources with fewer emissions could be selected. One more example, how to use freezer cabinets at selling points can be affected by behaviours of retailers and consumers. It is difficult to change their behaviours from Unilever side.

Theoretically, the biggest reductions in GHG emissions can be achieved through the utilization of renewable energy sources such as wind power, solar energy, geothermal heat and biogas. Ben & Jerry’s
has been using some amount of green electricity applied to ice cream production at Hellendoorn in the Netherlands (Sim, Garcia-Suarez, Marshall, & Mauser, 2009). However, this needs more analyses on cost-effectiveness from the business perspective and it also depends on the availability of green electricity. In reality there are only a few examples of renewable energy sources being used in the dairy industry (Bertsch 2007). Biogas utilization could be a reasonable choice as considering the supply chain of ice cream as a whole, i.e. anaerobic digestion can be applied on treating manure, wastewater from manufacturing, residues etc. In general, biogas production is one of the most cost-effective mitigation measures that simultaneously reduced emissions of several greenhouse gases from the whole production chain (Weiske et al., 2006). It has the ability to reduce on-farm emissions of methane and nitrous oxide, and to substitute at the same time the use of fossil fuels.

6.3 Planning the target market
Distributing ice cream to different terminal market can affect the carbon footprint of ice cream. Selling them in the nearer market in terms of the ice cream plant could result in less GHG emissions and energy use than in a farther market. For instance, Wuhan factory would produce ice cream to supply Chengdu market, between which the distance is around 1500 km. The carbon footprint from transportation would be 186 g CO_{2} equivalent per litre ice cream. However, if a new factory could be set up in Chengdu to meet the up-scaling demands, the carbon footprint caused by transporting ice cream would be dramatically decreased to 25 g CO_{2} equivalent per litre ice cream. Therefore, from the view of GHG emission reductions, optimally planning the market served by one factory could be an effective method to reduce GHG emissions. The shorter distribution distance implies lower climate impacts. Considering the complexity of practical conditions, optimising the market can be done in accordance with Unilever’s future plan.

6.4 Using liquid milk instead of milk powders
The stage of transporting fresh milk to milk products processors, processing milk powders and transporting milk powders to ice cream factories contributed not more than 4% of climate impacts of ice cream. However, these three stages used 10% of energy use of ice cream (see Figure 4 and Figure 7). The energy use in these stages include fossil fuels used for transporting fresh milk and milk powders, and electricity consumption and fuels combustion for drying milk powders.

It is interesting to analyse the energy flow among stages of transporting fresh milk, making powders and transporting powders to ice cream factories. Fresh milk is transported to powder processors. Water is evaporated from fresh milk. In the meanwhile, fresh milk is kept with a low temperature in the cooling lorry, so more energy has to be used in the drying process. However, milk powders at ice cream factories would be mixed with water again and then cooled again to the lower temperature for producing ice cream. Hence, these stages imply not only energy use but also energy waste. Therefore, using liquid milk as the raw materials could obviously decrease the climate impacts of ice cream compared to using milk powders. Decreasing the transportation among these stages was also clearly helpful to the reductions. For instance, ice cream factories would use milk powders produced on large-scale dairy farms and purchase these powders of a distance of 2000 km. This process implied 70 g CO_{2} equivalent and 1.13 MJ per litre ice cream. Whereas if fresh milk was directly transported from the farms to the ice cream factories, the climate impacts could be lowered to 8 g CO_{2} equivalent and the energy use would be only 0.14 MJ per litre ice cream. The difference is a factor of 8.

Ben & Jerry’s has already used skimmed milk and cream in the ice cream production. This does help to save energy for the production and transportation of milk powders and cooling milk in factories, on one hand; on the other hand, it is also helpful to save large amounts of water. This way requires more sophisticated temperature-controlled handling, because ice cream made with fresh milk and cream is extremely sensitive to contamination and requires storage at – 26°C cold chain from the factory to the consumer (Burke & Wingard, 1997). Moreover, the distance between the dairy farms and ice cream factories is also a crucial factor, but it can be balanced through optimizing the distance between dairy source and ice cream factories.
7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Overall, production one litre ice cream (only based on milk, excluding other ingredients) in China implies a carbon footprint of 1.2-1.8 kg CO2 equivalent and energy use of 5.8-10.5 MJ. Three stages of milk production on farms, manufacturing in plants and storing at selling points were found to be the hotspots of the chain. Carbon dioxide is the main GHG which has a significant influence on and contributes about 80% of the total carbon footprint. The most effective and pragmatic measures to decrease the climate impacts of ice cream from the perspective of ice cream chain for Unilever are as follows: mitigating the GHG emissions from dairy farms through effective manure management, replacing utilization of milk powders with liquid milk, optimally planning the point of manufacturing to market served, and transforming energy mix through utilization of green energy.

7.2 Recommendations for future study

Besides large amounts of milk powder used for ice cream production some other ingredients such as sugar, eggs and chocolate dependent on people’s flavours are also needed. Producing these kinds of materials can also result in large quantities of GHG emissions. Future study should include these ingredients and make the results more reasonable.

Although some reports studied on-farm emissions based on life cycle assessment, there are no relevant studies over dairy farms in China. This study substituted relevant data with dairy farms of New Zealand and the Netherlands. It can lead to over-assessment or less-assessment on GWP, because the practical production conditions in China are different. Therefore, research for the life cycle assessment of China’s dairy farms from cradle to farm-gate is essential. The same holds for other factors such as producing milk powders.

Ingredients for ice cream production can be varied with the changes of flavours. The results of this study were based on the mass balance in 2008 to gain an overall insight into ice cream production in China. Future study can mainly focus on one or several types of ice cream.

The methodologies were used to assess the carbon footprint of ice cream production in China in 2008. However, they are also suitable to ice cream factories in any country. This study did not lead to concrete policy recommendations but would rather identify a number of issues that merit further tailor-made investigations based on practical conditions in China. It will also contribute to a more detailed debate on policy proposals within different parties of Unilever.
REFERENCES


IPCC. (1996). Climate change 1995: the science of climate change – contribution of working Group I to the second assessment of the intergovernmental panel on climate change. In Houghton, J.T.,


## APPENDICES

### Appendix 1 Distribution of dairy processing enterprises

Distribution of processing manufacturing of Top 8 dairy processing enterprises 2005 in China.

<table>
<thead>
<tr>
<th>Enterprise name</th>
<th>District</th>
<th>Number of processing factories</th>
<th>Daily processing capacity (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sanyuan</td>
<td>Beijing</td>
<td>7</td>
<td>1227</td>
</tr>
<tr>
<td></td>
<td>Tianjin</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Inner Mongolia</td>
<td>2</td>
<td>350*</td>
</tr>
<tr>
<td></td>
<td>Shanghai</td>
<td>2</td>
<td>130</td>
</tr>
<tr>
<td>Bright</td>
<td>Beijing</td>
<td>4</td>
<td>360</td>
</tr>
<tr>
<td></td>
<td>Tianjin</td>
<td>1</td>
<td>300</td>
</tr>
<tr>
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<td>Heilongjiang</td>
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<td>1000*</td>
</tr>
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</tr>
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<td>3750</td>
</tr>
<tr>
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</tr>
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<td>1</td>
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</tr>
<tr>
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<td>Hunan</td>
<td>1</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Guangdong</td>
<td>1</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>Shanxi</td>
<td>1</td>
<td>200</td>
</tr>
<tr>
<td>Mengniu</td>
<td>Beijing</td>
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<td>250</td>
</tr>
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<td>2</td>
<td>5700</td>
</tr>
<tr>
<td></td>
<td>Henan</td>
<td>1</td>
<td>800</td>
</tr>
<tr>
<td>Yili</td>
<td>Beijing</td>
<td>1</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>Hebei</td>
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<td>360*</td>
</tr>
<tr>
<td></td>
<td>Inner Mongolia</td>
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<td>5600*</td>
</tr>
<tr>
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</tr>
<tr>
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<td>Heilongjiang</td>
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<td>240*</td>
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<td>Shanxi</td>
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</tr>
<tr>
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</tr>
<tr>
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<td>Liaoning</td>
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<td>Heilongjiang</td>
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<td>Shandong</td>
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<td></td>
<td>Shanxi</td>
<td>1</td>
<td>180*</td>
</tr>
<tr>
<td>Sanlù**</td>
<td>Hebei</td>
<td>10</td>
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<td></td>
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<td></td>
<td>Jiangsu</td>
<td>4</td>
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</tr>
<tr>
<td></td>
<td>Anhui</td>
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<td>50</td>
</tr>
<tr>
<td></td>
<td>Jiangxi</td>
<td>1</td>
<td>70</td>
</tr>
</tbody>
</table>


*These factories produce milk powder besides manufacturing other milk products.

**Sanlù declared insolvent to go bankrupt because of the melamine scandal. Sanyuan won the bidding for Sanlù assets (Xinhua, 2009).
Appendix 2 Distance of transporting milk powders

The map of China showing the location of Beijing, Wuhan, Shanghai (Taicang factory is 50 km far away) and Hong Kong.

Rough distances between milk products processors and ice cream plants for transporting milk powders.

<table>
<thead>
<tr>
<th>Enterprises</th>
<th>Location of ice cream plants</th>
<th>Distance (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mengniu, Yili (Huhehaote, Inner Mongolia)</td>
<td>Beijing</td>
<td>425</td>
</tr>
<tr>
<td></td>
<td>Taicang</td>
<td>1340</td>
</tr>
<tr>
<td></td>
<td>Wuhan</td>
<td>1160</td>
</tr>
<tr>
<td>Bright (Shanghai)</td>
<td>Beijing</td>
<td>1060</td>
</tr>
<tr>
<td></td>
<td>Taicang</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Wuhan</td>
<td>690</td>
</tr>
<tr>
<td>Wandashan (Heilongjiang)</td>
<td>Beijing</td>
<td>1060</td>
</tr>
<tr>
<td></td>
<td>Taicang</td>
<td>1660</td>
</tr>
<tr>
<td></td>
<td>Wuhan</td>
<td>1998</td>
</tr>
<tr>
<td>Nestle (Shuangcheng, Heilongjiang)</td>
<td>Beijing</td>
<td>1166</td>
</tr>
<tr>
<td></td>
<td>Taicang</td>
<td>2221</td>
</tr>
<tr>
<td></td>
<td>Wuhan</td>
<td>2345</td>
</tr>
<tr>
<td>Sanyuan (Beijing)</td>
<td>Beijing</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Taicang</td>
<td>1070</td>
</tr>
<tr>
<td></td>
<td>Wuhan</td>
<td>1085</td>
</tr>
<tr>
<td>Sanlu *(Shijiazhuang, Hebei)</td>
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<td>260</td>
</tr>
<tr>
<td></td>
<td>Taicang</td>
<td>950</td>
</tr>
<tr>
<td></td>
<td>Wuhan</td>
<td>830</td>
</tr>
</tbody>
</table>

Source: Google (2009).
* Sanlu declared insolvent to go bankrupt because of the melamine scandal. Sanyuan won the bidding for Sanlu assets (China Retailer News, 2009; Xinhua, 2009).
The world map showing the rough distances between Oceania, North America, Europe and China.

<table>
<thead>
<tr>
<th>Start harbour</th>
<th>Destination harbour</th>
<th>Distance (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotterdam</td>
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</tr>
<tr>
<td></td>
<td>Shanghai</td>
<td>19296</td>
</tr>
<tr>
<td>Auckland</td>
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<td>10393</td>
</tr>
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<td></td>
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</tr>
<tr>
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<td>10966</td>
</tr>
<tr>
<td></td>
<td>Shanghai</td>
<td>10616</td>
</tr>
</tbody>
</table>

Appendix 3 Melamine Issue 2008 in China

The 2008 Chinese milk scandal was a food safety incident in China involving milk and infant formula, and other food materials and components, adulterated with melamine. Melamine is a chemical with rich nitrogen and can be illegally added into food products to enhance the protein content. When melamine enters into human body with food, it could cause renal and urinary problems in conditions that it reacts with cyanuric acid inside the body. The Ministry of Health said it was likely melamine contamination killed six babies. Another 294,000 infants suffered from urinary problems such as kidney stones (Xinhua, 2008).

The issue was initially centred on Sanlu, one of the largest dairy companies based in Hebei before bankruptcy, whose melamine-tainted infant milk powder had sickened a growing number of babies. Nationwide inspections later found that milk powder from 21 dairy enterprises including Mengniu, Yili and Bright were also contaminated (Zhao, & Lim, 2008).

This issue closely resulted from the supply chain of milk processing enterprises. Some companies can directly collect fresh milk from milking stations located on their own dairy farms. Others who have no dairy farms would purchase milk from independent local milking stations. Owing to the incentives of making more money and reducing their costs, the owners of these independent milking stations would have opportunities to adulterate the fresh milk by adding melamine to water-downed fresh milk. Furthermore, they may also collude with purchasing agents of dairy enterprises to provide tampered supply.