Assessment of Local Food Distribution

Challenges and Possibilities for Logistics Development

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Abstract

There is increasing interest in local food, as consumers feel confidence in such food. Local food has good opportunities to fulfil quality aspects/requirements of transparency and traceability in the supply chain due to the possibilities for direct interaction between producers and consumers. However, local food producers often face logistics challenges due to their small scale, decentralisation and integration difficulties with larger supply chains. This necessitates analysis of specific logistics systems in order to identify successful approaches for improving the local food supply chain. Important questions are whether local and small-scale food producers can transport their goods more efficiently and how they can improve distribution and its environmental impact.

This thesis examined local food distribution systems to determine how cooperation, optimisation and integration in the supply chain can make the distribution systems of local and small-scale food producers more efficient and to estimate the environmental impact of the transport. The work comprised a producer survey examining marketing channels and impediments to development in local supply chains in Sweden, three case studies on distribution systems of different scales and an analysis of the environmental impact of local food distribution, based on quantification of emissions and energy use. The case studies involved small-scale producers integrating their marketing and distribution into a large retail chain using an electronic trading system; the distribution of local food in and around a city; and a distribution system for municipal units in four municipalities.

Based on the results, distribution strategies for local and small-scale food producers and distributors were developed and refined. By mapping distribution systems and impediments to development, optimising routes and estimating emissions, potential improvements in the distribution system were identified. This revealed scope for local and small-scale food producers to improve their distribution and reduce their environmental impact. Cooperation, integration and route optimisation are suitable strategies for producers to adopt in order to make their transport more efficient.

Keywords: transport, local food, food producers, supply chain, distribution system, cooperation, integration, optimisation, emissions, energy

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Dedication

This book is dedicated to you, who are drawn to read it.

Adieu, dit le renard. Voici mon secret. Il est très simple: on ne voit bien qu'avec le cœur. L'essentiel est invisible pour les yeux.

Le Petit Prince, Antoine de Saint-Exupéry

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to in the text by Roman numerals:

Paper I: Nordmark, I., Ljungberg, D., Gebresenbet, G. & Cardoso, M. Distribution and marketing channels of locally produced food in Sweden (submitted)

Paper II: Nordmark I., Ljungberg D., Gebresenbet G., Bosona T. & Jüriado R. (2012). Integrated logistics network for the supply chain of locally produced food. Part II: Assessment of e-trade, economic benefit and environmental impact. *Journal of Service Science and Management* 5(3), 249-262.

Paper III: Gebresenbet G., Nordmark I., Bosona T. & Ljungberg D. (2011). Potential for optimised food deliveries in and around Uppsala city, Sweden. *Journal of Transport Geography* 19(6), 1456-1464.

Paper IV: Bosona, T., Nordmark, I., Gebresenbet, G. & Ljungberg, D. (2013). GIS-based analysis of integrated food distribution network in local food supply chain. *International Journal of Business and Management* 8(17), 13-34.

Paper V: Nordmark, I., Gebresenbet, G. & Ljungberg, D. Estimation of emissions and energy use in case studies of local food distribution (submitted)

Papers II - IV are reproduced with the permission of the publisher.

The contribution of Ingrid Nordmark to the papers included in this thesis was as follows:

Paper I: Project planning, data collection and data analysis in cooperation with co-authors, main responsibility for writing

Paper II: Part of data collection and analysis, main responsibility for writing

Paper III: Part of data analysis, particularly on unloading parameters, and participation in writing

Paper IV: Project planning, data collection, part of data analysis and writing

Paper V: Project planning, data collection, data analysis, main responsibility for writing

List of related publications, not included in this thesis:

Bosona, T., Gebresenbet, G., Nordmark, I. & Ljungberg, D. (2011a). Integrated logistics network for the supply chain of locally produced food, Part I: Location and route optimization analyses. *Journal of Service Science and Management* 4(2), 174-183.

Bosona, T., Gebresenbet, G., Nordmark, I. & Ljungberg, D. (2011b). Box-scheme based delivery system of locally produced organic food: Evaluation of logistics performance. *Journal of Service Science and Management* 4(3), 357-367.

Bekele, A., Bosona, T., Nordmark, I., Gebresenbet, G. & Ljungberg, D. (2012). Assessing the sustainability of food retail business: The case of Konsum Värmland, Sweden. *Journal of Service Science and Management* 5(4), 373-385.

Ljungberg, D., Gebresenbet, G., Nordmark, I., Bosona, T. G., Jüriado, R., Cardoso, M. & Redman, L. (2012). *Lokal matlogistik - Möjligheter till utveckling, effektivisering och integration med storskaliga logistikkedjor*. Internal report 55, ISSN 1654-9406. Swedish University of Agricultural Sciences.

Abbreviations

AP	Acidification potential
CC	Collection central
CO	Carbon monoxide
CO_2	Carbon dioxide
DC	Distribution central
EP	Eutrophication potential
GWP	Global warming potential
HC	Hydrocarbon
HTP	Human toxicity potential
LCA	Life cycle assessment
LDC	Local distribution centre
LSFDC	Large-scale food distribution chain
NO_X	Nitrogen oxides
PM	Particulate matter
SCM	Supply chain management
SO_2	Sulphur dioxide

1 Introduction

Local food has become very popular in recent decades, and it has been attributed to many positive characteristics. Distribution of local food is often believed to have a lower environmental impact than food which has travelled long distances. However, local producers are often small scale and have very limited resources to work on transport optimisation.

This thesis analyses the transport of local food with the aim of increasing the efficiency, in terms of driving times and driving distances, and reducing energy consumption and vehicle emissions on collection and distribution routes.

1.1 Consumer demand for local food

There is considerable interest in local food and the desire for more ‘local’, ‘alternative’ or ‘traditional/speciality’ foods is well reflected in academic publications (Ilbery & Maye, 2005[1]). Consumers commonly view local food as more genuine, natural and environmentally friendly, of higher quality and better in terms of employment in the countryside and rural development (Wretling Clarin, 2010; Feldmann & Hamm, 2015). Interest in maintaining open landscapes and protecting biodiversity are other reasons why people support local and smaller-scale production.

The increased interest in local, regional, traditional and seasonal food can be explained by factors such as those presented by Hughes (2003): globalisation awakening interest in returning to what is traditional and local; an ageing consumer population, as in the UK; concern for the environment and the large fuel use due to long transport distances; concern about the safety of

[1] Illbery & Maye (2005) mention a number of themed sections and special issues published in *International Planning Studies*,4 (3), 1999; *Sociologia Ruralis*, 40 (2), 2000; 40 (4), 2000; 41 (1), 2001; 42 (4), 2002; *Journal of Rural Studies*, 19 (1), 2003; *Environment and Planning A*, 35 (3), 2003 and the *British Food Journal*, 105 (8), 2003.

global food; a heavy media focus on food, re-acquainting consumers with their (real or imagined) cultural heritage; the pleasure of buying local food and, since expenditure on food is a relatively small part of the family budget (at least in wealthier parts of the world), local food can be “something special” that many can afford.

There is also a retro-trend, described by Hughes (2003), including major retailers wanting to stock unique local and regional products; a renaissance in farmers’ markets; leading edge initiatives serving to reinforce the importance of local and speciality foods; offering special products as a way for restaurants and others to distinguish themselves from the mainstream; a saturated global market forcing producers to seek higher value market opportunities; information technology (IT) development simplifying the connection between small-scale producers and large-scale customers; and pressure from customers, lobbyists and competitors.

There is no general definition of local food (Jones, Comfort & Hillier, 2004; Hallberg & Granvik, 2013; Eriksen, 2013), although some organisations have definitions regarding food produced and consumed within a certain distance. Some examples are “Local Food Plus” in Canada, which uses provincial boundaries (Campbell & MacRae, 2013), and “Bondens egen marknad”, a farmers’ market in Sweden with a limit of 250 km,[2] although in northern Sweden (in the largest county, Norrbotten) the market is open to products from all over the county (Kask, 2012), with distances up to around 400 km accepted. Proposals on how to use the term ‘local food’ are being evaluated in Sweden (Hallberg & Granvik, 2013) focusing on transparency in the food production.

Recognising the difficulties in finding a strict definition covering all relevant aspects of the term, this thesis considers local food as *food produced and consumed within the same geographical region*. However, the definition of a region varies and is dependent on what the consumers refer to as local.

1.2 Constraints in local food supply

Consumers are increasingly concerned about food safety and quality, including food-borne illness, humane animal treatment, genetic modification and overall product safety and integrity. As a consequence, there is increased interest in the transparency of food supply chains. Places and modes of production and traceability as aspects of food quality have gained in importance in recent decades.

The interest in supporting farming and businesses in the countryside comes both from consumers and from society. The United States Department of

[2] Bondens egen marknad, Info, http://bondensegen.com/page.php?page=info, 2012-06-14

Agriculture has policies to improve school food quality while protecting the environment whereby local foods, especially fruit and vegetables, are promoted for health reasons and in order to support local farmers (Wunderlich, Bai & Chung, 2013). A number of municipalities in Sweden want to increase the amounts of locally produced food in municipal catering units, such as schools, pre-schools and homes for the elderly.

In many stores, local products are promoted due to customer demand. This has aroused interest in local food production using local resources and inputs. Hence, local food production may represent a strategic value aspect that farms and other small-scale food processing firms can exploit in their business initiatives and marketing efforts. Small-scale local producers can offer quality products (traditional recipes, artisan products) and stress the importance of product origin and transparency of the food chain as competitive factors.

For producers, a number of factors are important in the food supply chain, such as quality, technology, logistics, information technology, the regulatory framework and consumers (Bourlakis & Weightman, 2003). Food products must be of good quality, safe, healthy and traceable (food traceability has been mandatory within the EU since 2005[3]).

Gebresenbet & Bosona (2012, p. 127) point out that "In local food systems, the distribution infrastructure is partial, fragmented and often inefficient, as in non-centralised distribution, the share of the transport cost per unit of the product is relatively high".

For producers spread over a large geographical area and with large distances to the consumers, maintaining identity can be a problem. The ongoing process of global urbanisation is helping to increase the distance between customers and agricultural areas. Although the closeness to the customer is a main advantage (and prerequisite) in local food, in short supply food chains it can also be a hindrance for the producers. For example, in densely populated areas, such as around Paris, producers face obstacles due to land scarcity, lack of organisation and labour shortage (Aubry & Kebir, 2013).

Today, small-scale producers deliver their produce directly to retailers and it may take almost a day to deliver small portions of produce. These are expensive modes of delivery, both in terms of time and money. The question may then arise of finding the best and simplest delivery choice available to small-scale farmers. In Sweden, the large-scale food system for food retailing has been restructured into fewer, more efficient distribution facilities and the trend towards centralisation is clear (Storhagen, Bärthel & Bark, 2008). The question is whether it is possible for local food to make use of professional distribution systems on a local, regional or national scale. Table 1 summarises

[3]Regulation (EC) No 178/2002

the societal demand for local food, its advantages, potential constraints and possible solutions.

Table 1. *Values, constraints and possible solutions associated with the local food supply chain*

Perceived values in consumer demand	Constraints related to logistics for producers	Possible solutions
· Promote employment · Environment · Promote lifestyle in countryside · Promote animal welfare · Food quality and security · Tasty food · Organic food · Transparency · Promote regional food tradition · Tourist attraction	· High logistics costs, including management, billing and transport · Seasonality /discontinuity in the marketing chain · Environmental impact · Insufficient baseline data and scientific analysis of local food	· Develop new logistics system for local food supply - integration within local food supply system - integration with large scale supply - focus on reducing costs - focus on reducing environmental impact · Collect and analyse scientific data

1.3 Sustainability and local food

The term 'sustainability' is widely used and often based upon the Brundtland Commission's statement that: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). This very wide definition is nowadays often referred to as the integration of social, environmental and economic responsibility (Lehtinen, 2012), also called the triple bottom line (TBL). This concept was developed during the mid-1990s and refers to the fact that companies and other organisations have created values in several dimensions, but can also destroy values (Elkington, 2006).

So far, supply chain management (SCM) has mainly focused on economic sustainability, but the other aspects, especially environmental sustainability, are now being incorporated in SCM (Seuring & Müller, 2008). Several terms and definitions are used to describe the sustainability management in SCM. Some examples are "green supply chain management" (GSCM), "sustainable supply chain management" (SSCM), "environmental supply chain management" (ESCM) practices and "green management practices" (GMP). Integrating sustainability in supply chain management can have long-term economic benefits and can provide a competitive advantage, as well as having positive effects on the environment and society (Carter & Rogers, 2008).

The sustainability of local food, mainly due to the proximity to producers, is often used as a sales argument. However, locally produced food is not automatically better for the environment than non-local food just because it is produced closer to the end customer (Ilbery & Maye, 2005; Wallgren, 2006) and criticism has been directed at the use of distance (often called "food miles") alone as a measurement of the environmental impact of transport (Coley, Howard & Winter, 2011; Johard *et al.*, 2012). Studies comparing transport of local food and non-local food have so far not been able to determine which is better in environmental terms (Wallgren, 2006; Van Hauwermeiren *et al.*, 2007).

So far, the food availability in Sweden is good and there is a low risk of food insecurity (Maplecroft, 2009). This involves a strong reliance on imported food, which is not necessarily bad. However, as Deutsch (2004) argues, it includes reliance on ecosystems in other countries and it is therefore important for food security to care not only about the domestic ecosystem, but also about those in other countries.

The transparency of food produced nearby can be higher than that of food produced far away, which can be advantageous for locally produced food. The increased use of globalised systems for food production has increased reliance on other nations. In Sweden, over one-third of food consumption requires agricultural areas abroad (Deutsch, 2004) and 74% of manufactured animal feed is imported (Deutsch & Folke, 2005). This has an impact on distant ecosystems and, as Deutsch (2004) stresses, it is important to have an understanding of these effects in order to secure food production and support these ecosystems. This principle should be applied no matter whether food is being produced nearby or far away.

1.4 Transport sector – energy and emissions

The transport sector uses a great deal of energy, has a major impact on the environment and is strongly dependent on fossil fuels. Transport represents 27% of total energy consumption in the world (IEA, 2012) and road transport in particular is a major contributor to environmental pollution (Uherek *et al.*, 2010). In the OECD countries, the cost of the health impact from outdoor air pollution was about USD 1.7 trillion in 2010, and road transport is estimated to account for about 50% of that cost (OECD, 2014).

In Sweden, the transport sector uses approximately 85 TWh, corresponding to 23% of the country's total energy use[4] (Swedish Energy Agency, 2015). Most of the energy in the Swedish transport sector (93%) is used in road transport (*ibid*.). Fossil fuels, mainly petrol and diesel, dominate and renewable fuels only make up only a few per cent. The goods sector mainly uses diesel and the passenger sector mainly petrol. The use of petrol in Sweden has decreased in recent years, while diesel use has increased considerably since the beginning the 21st Century (Bergström, 2015).

The energy used in the food supply system in Sweden[5] is about 34 TWh (in 2000) according to Wallgren & Höjer (2009). Transport's share of total energy use in the supply chain is 14% (4.9 TWh in 2000). Transport involving use of private cars for shopping represents a large amount (2.0 TWh) of this energy use – an interesting phenomenon, but one which is not analysed in this thesis.

Of the total emissions from energy use in Sweden, emissions from transport (in 2009) comprised 43% carbon dioxide (CO_2), 10% sulphur dioxide (SO_2) and 53% nitrogen oxides (NO_X) (Swedish Energy Agency, 2012). In the energy sector (including industry, transport, residential, services *etc*., electricity and district heating, fugitive emissions from fuels), transport is the largest contributor to CO_2 and NO_X and the third largest to SO_2 (see Figure 1).

1.5 Environmental effects

Typical environmental impacts connected to vehicle emissions are the global warming, acidification, eutrophication and human toxicity potentials. Within life cycle assessment (LCA), the potential environmental impact of products, services or systems is estimated. LCA is standardised methodology (ISO 14040 and 14044) used to estimate energy balance and emissions to air, water and soil (ISO, 2006a, 2006b). Principles of LCA methodology can be applied to parts of a supply chain, such as in the distribution phase. Emissions amounts from distribution can be estimated with emissions factors (*e.g.* from Trafikverket, 2015) or within tools such as the Network for Transport and Environment (NTM) freight calculator (NTM ,2014).

The contribution of transport to the total supply chain's environmental impact may be minor. This is often the case in meat supply chains. Weber & Matthews (2008) reported for red meat in the US, that while the distribution only accounted for 1% of the total life cycle emissions of greenhouse gases

[4]Energy use excluding international transport, non-energy purposes (raw materials for the chemical industry, lubricating oils and oils used for surface treatments in the building and civil engineering sectors, *etc*.), conversion and distribution losses and losses in nuclear power stations.

[5]Based on food consumption by Swedes rather than the Swedish food production system.

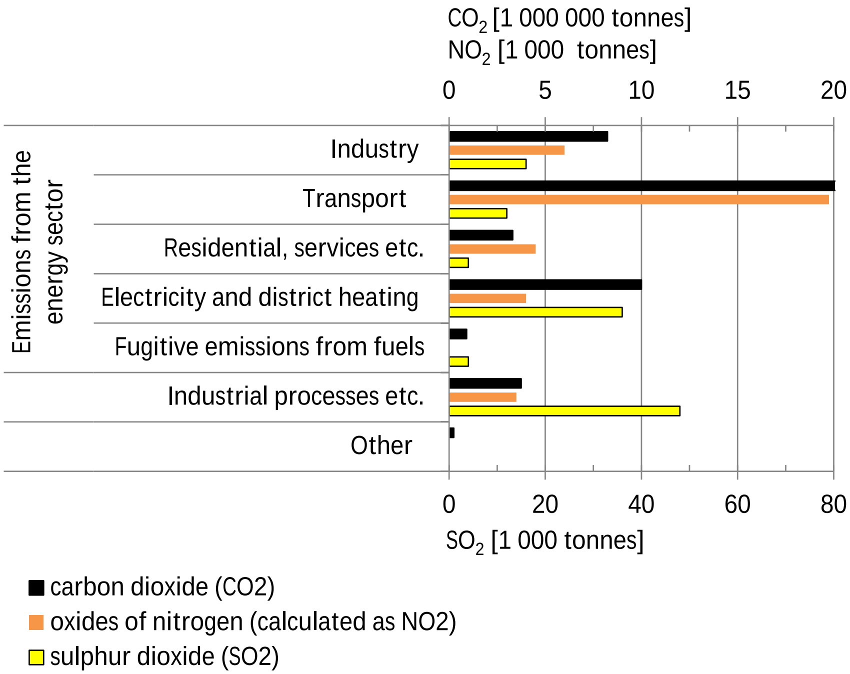

Figure 1. Emissions of carbon dioxide (CO_2), oxides of nitrogen (calculated as NO_2) and sulphur dioxide (SO_2) in Sweden in 2009 (Swedish Energy Agency, 2012)

(GHG), the corresponding value for fruit and vegetables was 11%. Foster *et al.* (2006) found that for the beef supply chain, transport produces 3-5% of the supply chain's global warming impact and energy consumption. In a LCA of Swedish pasta, the distribution rendered 8 g CO_2e/kg pasta, corresponding to 1.6% of the GHG emissions (Röös, Sundberg & Hansson, 2011). In other supply chains the contribution is greater. In a LCA of peeled potatoes in the United Kingdom, distribution to retailers represented 12% of energy use, contributed 1% to acidification potential and 15% to climate change impact. In a bread supply chain in Sweden,[6] transport represented up to 39% of the chain's contribution to global warming, 46% of acidification and 10% of eutrophication (Foster *et al.*, 2006). In a LCA of potatoes in Sweden, Röös, Sundberg & Hansson, (2010) found that distribution represented 12% of the carbon dioxide equivalents (14 g CO_2e/kg potatoes) in the lifecycle.

The most common way of estimating global warming potential (GWP) is using the method proposed by the Intergovernmental Panel on Climate Change (IPCC) with a 100-year perspective (GWP100). The use of GWP100 is not

[6]Life cycle study of a large industry bread supply chain that included primary production-agriculture, processing- milling and baking, transportation and the consumer-in the home.

unchallenged, however (Fuglestvedt *et al.*, 2003). Prioritising global warming potential only may lead to an increase in other environmental burdens (Webb *et al*., 2013), with calls for the inclusion of other potentials too.

Acidification is caused by elevated amounts of protons in the ground or water, *e.g.* from sulphur dioxide in fuel emissions. Eutrophication is caused by increased amounts of *e.g.* nitrates and phosphate from fertilisers in agriculture and from fuel emissions. The degree of toxicity to humans is the "degree to which a chemical substance elicits a deleterious or adverse effect upon the biological system of humans exposed to the substance over a designated time period" (Institute for Environment and Sustainability, 2012).

Small fragments of material called 'particulate matter' (PM), usually under 10 micrometres in size, are emissions that often cause problems for the human body. Particulates are emitted from the combustion of fuel and from the wearing away of roads and tyres. Combustion emits small particulates, while wearing results in larger particulates. Particulates are a cause of increased illness and mortality and are connected to heart and lung diseases (Naturvårdsverket, 2011).

For large companies, the estimated emissions from transport can be accounted for in a sustainability report, together with the results from the rest of their activities. Smaller companies do not have the same regulatory requirements (EC, 2014), or the capacity to perform the calculations and draw up the accounts. Simple ways of reporting the environmental impact from activities in a small company should be available. Complete reporting of the whole company's activities, *e.g*. Global Reporting Initiative (GRI) or other Corporate Social Responsibility (CRS) protocols, are in most cases too advanced and time-consuming for smaller companies.

1.6 Logistics as a tool for improving local food supply chains

What possible solutions are there for promoting more efficient transport and making economic and environmental improvements? Logistics is commonly referred to as a tool for bringing the right thing to the right place at the right time in the right condition. The Council of Supply Chain Management Professionals[7] has defined logistics management as:

[7]The Council of Supply Chain Management Professionals was previously the Council of Logistics Management (CLM), with the name changed in 2005 (MH&L, 2004).

> "… that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements." (CSCMP, 2015)

Supply chain management (SCM) is a broader term for the integration of supply and demand management within and across companies. The CSCMP's definition of SCM includes all logistics management activities mentioned above and the planning and management of all activities involved in sourcing, procurement and conversion. It also includes coordination and collaboration with channel partners such as suppliers, intermediaries, external service providers, and customers, in the process (CSCMP, 2015).

The definition's proposed driving force, the consumer requirements, has mainly been considered in terms of quality and cost. However, awareness of the environmental impacts from supply chains has recently increased.

In order to reduce the impact on the environment, transport can be made more efficient. With better route planning and increased load rates, distances can be shorter and vehicles used more efficiently. Using more efficient engines and efficient fuels are other parts of the solution. The source of energy and the energy carrier chosen for transport can have a large impact on emissions and on society's sustainability. Engaging external logistics providers can be one way of switching to more environmentally friendly distribution. Intermodal transport, such as combining road and rail, can also reduce emissions due to increased use of energy-efficient trains and reduced mileage in fossil-fuelled trucks.

Van Hauwermeiren *et al.* (2007, p. 45) concluded from their comparison of local versus mainstream food systems that "Local food systems can be much more sustainable by increasing their efficiency through optimising their transport and storage by diminishing the transport distance and storage time to a strict minimum and by increasing the stored and traded quantities to a full storage room and a full loaded transport mode."

Hughes (2003) describes the ideal supply chain as short, fast, transparent and seamless, with few links in the chain and close contact between company and customer. However, in practice the chain often appears to be the opposite: complex, price-driven, confrontational, disjointed and opaque. Vorst, Tromp & Zee (2009) point out that proper design of a food supply chain involves not only improved logistics, but also preservation of food quality and environmental sustainability. In a supply chain, it is more important to cooperate in order to create the most competitive chain than to compete for individual company profits (Christopher, 1998).

Cooperation, integration and optimisation are useful when improving logistics and finding economic and environmental improvements in supply chains.

Cooperation, coordination and collaboration can be seen as three levels of business interaction. In cooperation, firms exchange essential information and engage suppliers/customers in longer-term contracts (Spekman *et al*., 1998). Coordination is a deeper form of cooperation with more information linkages. Workflow andinformation is exchanged between the trading parties in a way that enables systems such as JIT (Just in Time) and EDI (Electronic Data Interchange), which attempt to make traditional linkages seamless (*ibid*.). Collaboration requires even more trust and commitment and includes future visions (*ibid*.).

It is more common to have vertical than horizontal cooperation (Daffy & Fearne, 2003), where vertical is defined as partnership between companies at different stages, upstream or downstream, in supply chains and horizontal is partnership between members in different supply chains. Combining routes and sharing transport are examples of horizontal cooperation (see Figure 2).

Integration in the supply chain involves (Bagchi & Skjott-Larsen, 2002):

- Information integration (sharing information and knowledge among members of the supply chain, including sales forecasts, production plans, inventory status and promotion plans)
- Coordination and resource sharing (realigning decision-making and responsibility in the supply chain)
- Organisational relationship linkage (communication channels between members of the supply chain, performance measurement and sharing common visions and objectives.

The objectives of integration are to reduce administration work, increase accuracy in information, facilitate integrated planning and support traceability. Fully integrated supply chains are popular as a concept, but there are few examples of truly integrated chains (Daffy & Fearne, 2003). Instead of developing a close connection between all firms in the supply chain, it might be more suitable to develop relationships in pairs (*ibid*.). Companies in a supply chain would then focus on the companies with which they have direct contact.

Optimisation can be employed as a tool for increased transport coordination. It can be used to find more efficient logistics solutions with optimal locations and efficient routes. There are several types of commercial software available for route planning and optimisation. Tools for vehicle routing problems (VRP), which were first described by Dantzig & Ramser (1959), can be very useful when planning the shortest time or distance and

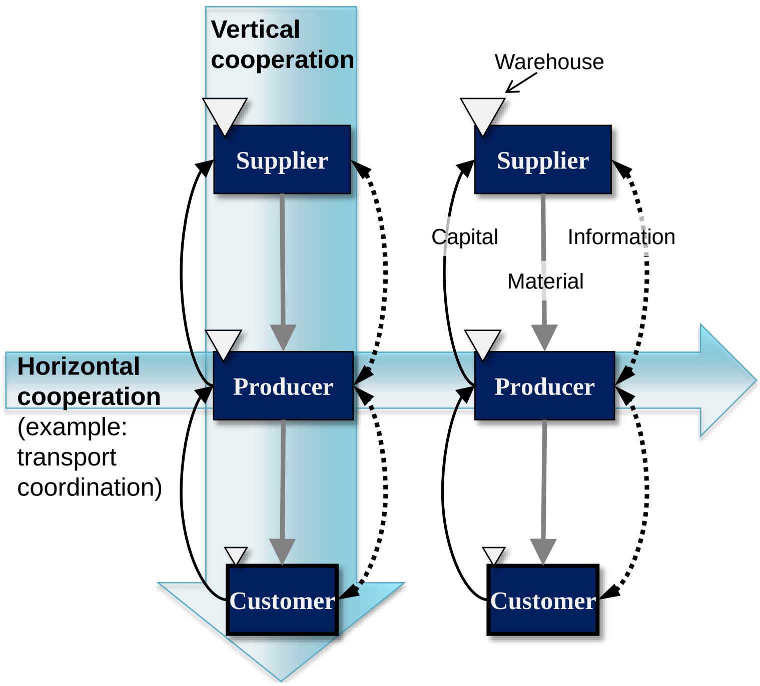

Figure 2. Supply chains showing the flow of capital, material and information. The cooperations illustrated here are vertical, along the supply chain, and horizontal, between firms at the same stage across supply chains.

fulfilling all the demands of delivery timing and working conditions, especially for larger vehicle fleets. It is also possible to find good locations for warehouses and valuable knowledge when restructuring or evaluating a distribution system.

Even though the impact of transport in total food supply chains may be minor, food transport is essential. Society has to plan for this and cannot expect this transport to be entirely replaced or not needed. The concept of eating and the need for food are so very basic and so critical that the transport of food can be seen as one of the most important types of transport. The fact that people in general no longer grow their own food and that the food market has become more globalised has contributed to making it even more essential. Given people's increased awareness of the impact of human activities on the environment, we are also more aware of the need to reduce some of these activities. Emissions play an important part in this regard and most emissions come from the transport sector.

There are many other reasons for making transport more efficient and less dependent on fossil fuels. Global agreements in order to achieve more sustainable development have been in place for some decades, with one highlight being the UN conference in Rio de Janeiro in 1992. The Swedish government has set a high target for the national vehicle fleet: by 2030, Sweden will have a rolling stock that is independent of fossil fuels (Miljödepartementet, 2009).

In order to make a system more efficient, it is important to have knowledge of that system. Bloom & Hinrichs (2010, p. 10) express this as follows: “By identifying and evaluating diverse distribution models for local and regional foods, we can better recognise and support the changes in institutions, enterprises and individuals that offer promising pathways to a more sustainable food system”.

The lack of a general definition of local food is a problem when seeking general statistics describing the producers in the sector. Therefore information is more likely to be found in case studies. Examples of studies of local food producer mapping can be found in Western European countries such as Great Britain (Ilbery *et al.*, 2006) and Finland (Töyli *et al.*, 2008; Lehtinen, 2012), as well as in developing countries such as Honduras (Blandon, Henson & Cranfield, 2009). There has been some mapping of small-scale producers in Sweden based on surveys (LRF, 2007; Björklund *et al.*, 2008; Wretling Clarin, 2010).

The outset of this thesis is that it is possible to make the distribution of local food more efficient and reduce its environmental impact. This raises a number of related questions, including: how to reach sustainability in the branch of local food; whether local food can compete with conventional food in a sustainable way regarding transport; what local food producers consider to be the main problems related to their transport; whether these producers can make their logistics system more efficient; how they can improve the logistics systems through cooperation and integration; and whether they can estimate the efficiency of their distribution system and its environmental impact.

There is a need to map out and evaluate distribution systems for local food in order to identify more efficient transport solutions and to find economic and environmental improvements in the local food supply chain. This thesis assessed local food logistic systems first by national surveys and then in case studies with systems of different scales in Sweden. During the case studies, different ways of transport cooperation, route optimisation and logistics integration were studied. The environmental impacts, mainly as emissions, were estimated in these case studies and emissions estimation tools available for smaller companies were assessed.

2 Objectives and structure of the work

The aim of this thesis was to assess local food distribution systems, to analyse whether cooperation, optimisation and integration in the supply chain can make local and small-scale food producers' distribution more efficient, in terms of driving distances and time, and to estimate the environmental impact of transport in local food chains. Specific objectives were to:

- Map out and analyse the supply and marketing channels of locally produced food in Sweden, and identify impediments to development in the supply chains (Paper I)
- Assess the e-trade system, the economic benefits and the environmental impact for small-scale local food producers integrated in a large-scale food supply chain (Paper II)
- Identify possibilities for coordinated goods distribution for food producers in and around a city (Paper III)
- Evaluate the performance of an integrated logistics network of a municipal local food distribution system (Paper IV)
- Estimate emissions and energy use for distribution in a number of case studies of locally produced food and identify existing tools for emissions and energy calculations suitable for small-scale food producers (Paper V).

The research was based on the logistics performance in several local food distribution systems and was structured as shown in Figure 3. A national survey was used to analyse the supply and marketing channels among Swedish local food producers. Distribution systems of different scales were studied, ranging from a vegetable box system to a group of small-scale producers integrated with a retail chain, city logistics with local transport and food companies, and a distribution system for municipal units in four municipalities.

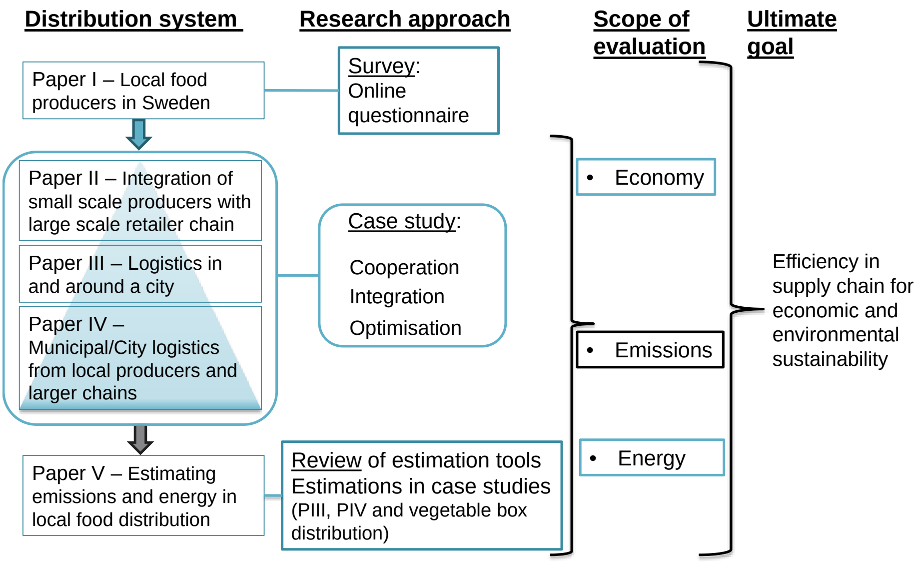

Figure 3. Structure of the work performed in Papers I-V of this thesis.

Paper I reports the results of the survey among local food producers in Sweden. An internet-based questionnaire was answered by 77 (in 2008) and 265 (in 2013) producers. The questions concerned their production, distribution, cooperation and business development. The main focus was marketing channels and distribution systems in local food supply chains.

Paper II describes cooperation between a group of producers in Halland and integration of their product deliveries with the distribution system of a large retail chain. The retail company integrated small-scale producers into its supply chain by including them in its electronic ordering system and physical distribution chain. Coordination of transport between the producers centred on a common collection centre (CC), before transport to the retailer's distribution centre (DC). The electronic trading system, developed specifically for the project[8], was based on cloud services, so the only equipment the producers needed was a computer with an internet connection and a printer. The electronic trading system introduced was assessed, together with the economic benefits of the new distribution system. Emissions and the potential environmental impact were estimated from an optimisation analysis with four scenarios for distribution (Bosona *et al.*, 2011a).

Paper III examined the distribution system for a number of companies in and around the city of Uppsala and the possibilities of developing a coordinated food distribution system. Based on field studies, interviews and a

[8]Developed by the software company Expert Systems, http://www.expertsystems.se/

series of seminars with stakeholders, optimisation of routes was performed. The routes from eight companies were mapped and optimised as individual routes and multiple routes. Emissions from the routes were estimated before and after optimisation.

Paper IV evaluated the performance of the integrated logistics network of four municipalities in Dalarna. From the data collected, a location analysis was performed in order to find the most suitable location for a distribution centre (DC). Route optimisation was performed in order to compare four distribution scenarios. Emissions and the potential environmental impacts were estimated for each of the scenarios.

Paper V estimated the emissions and energy use in local food distribution systems. Three systems were included, located in Roslagen (organic vegetable box system described by Bosona *et al*. (2011b), Ljungberg *et al*. (2012) and Redman (2010)), Uppsala (Paper III) and Borlänge (Paper IV). Through a review of freely available existing online tools for emissions and energy calculations, a few tools were identified that can be suitable for small-scale food producers.

2.1 Limitations

In the process of mapping out local food producers, the limited official records and the lack of a precise definition of local food limited the possibilities to make a controlled, randomised selection for more extensive statistical analyses.

In the case studies, the distribution systems were evaluated based on their logistics performance and environmental impact. The economic dimension of sustainability was only briefly addressed, and the social dimension was not considered.

In estimation of emissions and energy use, the focus was on impact from the process of using the vehicle fuel, not considering the process of producing and distributing the fuel, which should be included in an LCA.

The estimation of emissions and energy use per kilogram (kg) food delivered was based on observation of routes within a short time span, which limited the possibilities to identify variations in the routes.

3 Methodology

3.1 General approach

An explorative and descriptive research approach was used in this thesis, with a survey (Paper I) and case studies (Papers II-V) as the main methods to collect data from the studied systems. The descriptive approach was justified to allow the logistics situation in local food supply chains to be described and different distribution strategies to be evaluated and compared. Since the combination of logistics and local food is still a new area, the explorative approach was justified in the data collection and development of new knowledge.

Case study as a method is especially useful when seeking answers to *how* and *why* questions and to maintain a holistic perspective (Yin, 2007). The survey method is more useful for research questions based on *who, what, where, how many* and *how much*, such as when gathering baseline data on the unspecified group of local food producers. The use of multiple data sources to describe the same phenomenon, often referred to as triangulation, is often recommended in case studies (Yin, 2007) in order to improve the reliability of the results when limited data sets have to be used. In this study, two or three of the following methods were used in the case studies: questionnaires, interviews, seminars, direct observations and archive records.

Locating local food is a tricky task, due to the many different definitions. With a strict definition, such as ‘organic food’, it is possible to identify the whole group and select a representative sample. In the present case this was not possible, however. Therefore for mapping out Swedish local food, a producer-orientated questionnaire survey was chosen.

3.2 Study areas

Local food producers from all 21 counties in Sweden were included in a survey mapping out their marketing channels and distribution (Paper I). The case studies were concentrated to the county of Halland (Paper II), in and around the city of Uppsala (Paper III) and the county of Dalarna (Paper IV) (see Figure 4). In Paper V, the case studies in Uppsala and Dalarna were included together with a case study of a vegetable box system in Roslagen (Bosona *et al.*, 2011b).

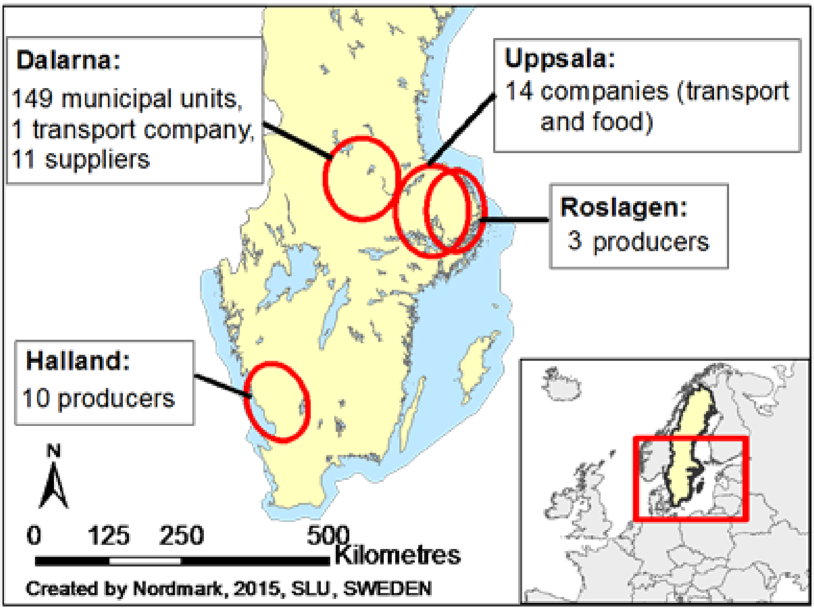

Figure 4. Map of study areas in Sweden: Halland (Paper II), Uppsala (Papers III, V), Dalarna (Papers IV, V) and Roslagen (Paper V).

3.3 Case studies

The main focus in the case studies related to the possibilities for cooperation, integration and optimisation for improvements in the logistics system (see Table 2). The following means were used in the distribution systems to cooperate and integrate: an electronic trading system (Paper II), transport coordination using common hubs (collection/distribution centres) (Papers II and IV), information sharing (Paper II-V) and engagement of a transport company (Paper IV). The level of cooperation and integration differed between participants in the case studies. In the cases in Papers II, IV and V the level of cooperation was high, while in the case in Paper III it was lower.

Table 2. *Summary of case study approach and participants (Papers II-V)*

	Halland (Paper II)	Uppsala (Paper III, V)	Dalarna (Paper IV, V)	Roslagen (Paper V)
Main participants:	**10 local producers** (fruit & vegetables, meat, egg, grain & bread, dairy, other), **retail chain**, **interest and business organisation**[a], **e-trade system company**	**Municipality**[b], **14 local companies** (3 transport companies, 5 bakeries, 3 meat distributors, 2 frozen food distributors, 1 flower distributor)	**4 municipalities**[c] with 149 delivery points (schools, pre-schools, homes for the elderly and people with disabilities), **transport company**, **11 producers** (local producers and national wholesalers)	**3 producers** (organic vegetable box) **transport company**
Quantities:	495 tonnes/year	n.a.	2761 tonnes/year	n.a.
Turnover:	195 MSEK/year	n.a.	n.a.	n.a.
Intended project outcomes:	Increase sales, improve logistics solutions, integrate local producers into retailer system	Demonstrate effective and environmentally friendly distribution	Evaluate system, increase number of local producers, improve logistics	Evaluate system and suggest improvements
Main focus:	Cooperation and integration	Cooperation and route optimisation	Cooperation, integration and route optimisation	Cooperation, (route optimisation)[d]
Main data sources (origin year):	Questionnaires, interviews (2008-2009)	Direct observations (38 routes), driver interviews, series of seminars (1998)	Interviews, archive records (2009-2010)	(Direct observations-5 routes, interviews) (2009)
Route optimisation:	(Route LogiX)[d]	Route LogiX	ArcGIS	(Route LogiX)[d]
Emissions estimation:	Emissions factors (Trafikverket, 2010)	MODTRANS	Emissions factors (Trafikverket, 2009)	Emissions factors (Trafikverket, 2009; Transportstyrelsen, (2010), VCA (2009)
Environmental impact:	CML, IPCC	-	CML, IPCC	–

n.a. = not available [a]Federation of Swedish Farmers, [b]Municipal population of Uppsala: 187 302, December 1998 (SCB, 2014). [c]Municipal population of Borlänge: 49 251, Säter: 10 840, Smedjebacken: 10 715, Gagnef: 10 097, December 2010 (SCB, 2014). [d]Route optimisation was performed within papers not included in this thesis. For optimisation details, see Bosona *et al.* (2011a) for Halland and Bosona et al. (2011b) for Roslagen.

The case studies were in different phases of development. Paper III examined the initial phase, with the first gathering of stakeholders and mapping of routes. Paper II addressed the pilot trial when implementing an integrated logistics network. Paper IV studied an up and running distribution system. Paper V focused on observed and reported distribution routes from three distribution systems.

3.4 Data collection

The producer survey (Paper I) was performed on two occasions (2008 and 2013). In the first part of the survey (S1), a questionnaire was sent to producers identified and selected from internet portals, lists of farm shops, websites for producers and producer networks and interviews with key individuals. In the second part of the survey (S2), producers listed on one of the largest websites for local food were surveyed.

The questionnaire in S1 was mainly internet-based (through the Mamut survey tool, http://www.mamut.com/), but telephone interviews and postal mail were used as additional response modes. The total number of respondents in S1 was 77. Some results from the survey are presented in Björkman *et al*. (2008).

For the second part of the survey (S2), a questionnaire was sent to producers registered at Food Map (*Matkartan*, http://www.regionalmat.se/matkarta.html). During the survey, this site was one of the lists of producers focusing on local markets. The internet-based survey tool Netigate (http://www.netigate.net/) was used for questionnaire distribution and data collection. The total number of responses in S2 was 265. The geographical distribution of the respondents is shown in Figure 5.

In the study in Halland (Paper II), data about the distribution system of a total of eight producers were collected through a questionnaire and interviews. In addition, data on producers' locations and delivery points, delivery frequencies, quantities and types of products and additional product distribution information were gathered. The economic indicators collected were turnover, transport costs and IT costs. The producers' initial situations were compared with the situation of small-scale food producers in Sweden according to Björklund *et al.* (2008).

Data collection in the study in Uppsala (Paper III) was performed by direct observations, including recording of activity times and GPS measurement of routes for eight of the companies involved. The parameters measured were company location, truck performance and time of distribution for all routes.

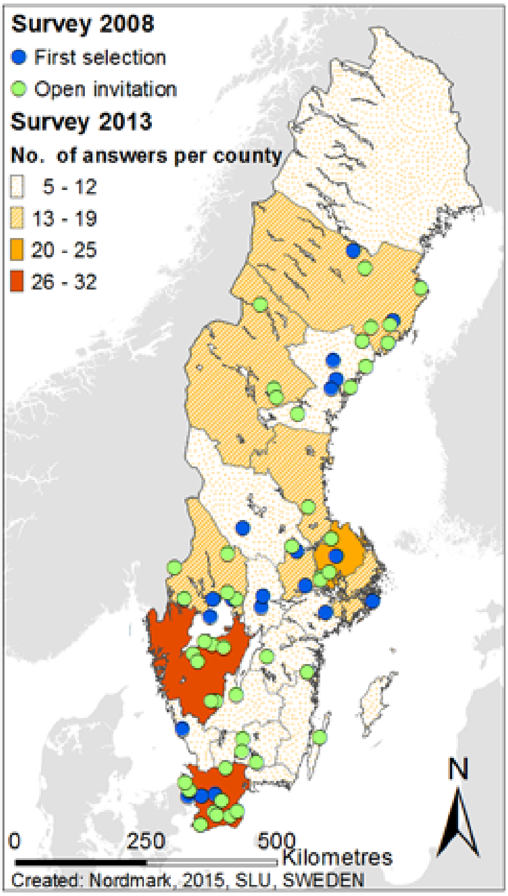

Figure 5. Geographical distribution of producers in the questionnaire survey (Paper I).

Interviews with the vehicle drivers gave insights into how the routes were planned and the order of priority. In parallel with field measurements, a series of seminars was held with the companies involved. The results from the study and possibilities of future cooperation were regularly discussed in the seminars.

In the study in Dalarna (Paper IV), the data sources were interviews and archive records. Summaries of orders (per week or month) and public procurement records gave detailed information on delivery addresses, frequencies, time windows, average and specified weight and temperature demands. Data were collected from the municipalities and the producers. ArcGIS software,[9] which is designed to handle geographical information, was used to plot the location of producers.

[9]ESRI, http://www.esri.com/software/arcgis/index.html, 2012-06-07

For estimating energy consumption and emissions in case studies in Paper V, distribution data were taken from Bosona *et al*. (2011b), Ljungberg *et al*. (2012) (Roslagen), Paper III (Uppsala) and Paper IV (Borlänge in Dalarna). Complementary data, such as weight of food delivered on individual routes, were found in background material from the case studies.

3.5 Route optimisation and location analysis

Based on details in the existing distribution systems, route optimisations were performed in Papers III and IV. In the case studies of Halland (Paper II) and Roslagen (Paper V), route optimisation was performed in papers not included in this thesis (for details see Bosona *et al*. (2011a) and Bosona *et al*. (2011b), respectively). However, the estimation of emissions in these cases (see section 3.6 Estimating environmental impact) was based on the optimisation study in Halland (Bosona *et al*., 2011a) and route observations in Roslagen (Bosona *et al.*, 2011b).

The route optimisation was performed using Route LogiX[10] (Paper III, Uppsala) and ArcGIS[11] (Paper IV, Dalarna). The Route LogiX software is a route planning system used in a number of companies, including the three largest food retail chains in Sweden (DPS, 2012). The software includes vehicle routing and optimises routes by minimising driving distance and time. The optimisation in the Uppsala case (Paper III) considered both single routes and combined routes based on distribution areas.

ArcGIS Network Analyst tools, including a VRP solver, were used in Paper IV. Working with the Network Analyst tools requires an existing road network. A road network was built in order to analyse the routes, based on the road map[12] (scale: 1:100 000) produced by Lantmäteriet as part of the GDS (Geografiska Sverigedata) map series. Speed limits provided by the Swedish Transport Administration[13] were applied.

The delivery routes in Borlänge municipality, where most of the municipal units were located, were analysed in order to find improvements and to test the road network built in ArcGIS. The entire system was then simulated in four distribution scenarios (see Figure 6):

[10] Software from DPS (Distribution Planning Software) International, http://www.dps-int.com/products/desktop/routing-software.php?ref=topNav, 2012-06-07

[11]Software from Esri, http://www.esri.com/software/arcgis, 2012-06-07

[12]Road map, http://www.lantmateriet.se/templates/LMV_Entrance.aspx?id=17406&lang=EN, 2012-06-11

[13]Trafikverket, http://www.trafikverket.se/

- Ø Scenario 1: A reference scenario in which all producers make their own deliveries to the municipal units (delivery points).
- Ø Scenario 2: In option I, all producers were assumed to deliver to the distribution centre (DC) themselves, while in option II the deliveries to the DC were partly correlated. Coordinated routes were then used to deliver food from the DC to the municipal units.
- Ø Scenario 3: Coordinated routes for collection to the DC and for delivery to municipal units.
- Ø Scenario 4: Coordinated routes for collection to the DC and for delivery to larger municipal units acting as local distribution centres (LDC).

A location analysis was carried out in Paper IV to evaluate the location of the distribution centre. This was based on the *centre-of-gravity technique*, *load-distance technique* and *location factor rating method* (Russell & Taylor, 2009).

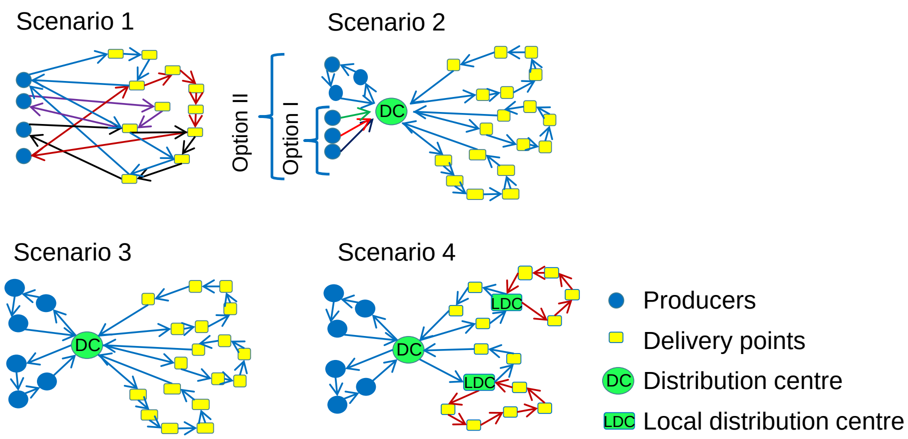

Figure 6. Scenarios in the study in Dalarna (Paper IV). Heavy trucks were assumed in general. Light trucks were assumed for local routes from local distribution centres.

3.6 Estimating environmental impact

Emissions in the studies were estimated using the MODTRANS model (Gebresenbet & Oostra, 1997) in Paper III and emission factors (Trafikverket, 2009, 2010) in Papers II and IV. The data collected on driving were more detailed in Paper III than in Papers II and IV. In Papers II and IV, emissions amounts were used to estimate and illustrate the environmental impact of the distribution systems. For conversion from amounts to impact characterisation factors, the Ecoinvent database was applied (Swiss Centre for Life Cycle Inventories, 2010a-b).

The emission estimations in Paper II were based on route analysis using Route LogiX, performed and described by Bosona *et al.* (2011a), where the producers' transport was compared according to four scenarios (see Figure 7):

- Scenario 1: Reference scenario: Producers distribute the products directly to the retail stores. Case A trucks and case B trucks and cars.
- Scenario 2: Producers deliver to a collection centre (CC), coordinated transport from the CC to the retailer's distribution centre (DC). Distribution from DC to stores, option I, in coordinated routes by light trucks, or option II, integrated in the retailer's existing routes assuming that products from the local producers would not constitute more than 30% of the load.
- Scenario 3: Similar to scenario 2, except for the first step, where collection routes to CC are coordinated.
- Scenario 4: Integrated collection and distribution of products managed via a communication centre.

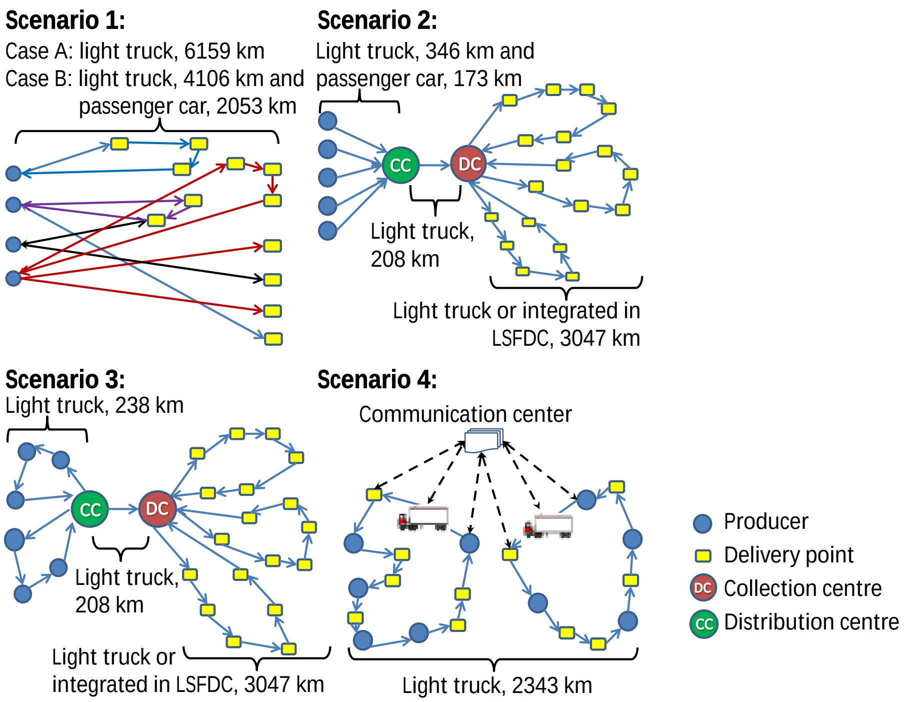

Figure 7. Scenarios from Bosona *et al.* (2011a) in the study in Halland (Paper II) with vehicle assumptions. CC denotes collection centre and DC denotes distribution centre. In scenarios 2 and 3, the distribution between the DC and the delivery points used light trucks in option I, and was integrated in the large-scale food distribution channel (LSFDC) in option II.

The study described in Paper V included estimation of emissions and energy use in routes from three local food distribution systems (see Table 3), previously described in Papers III, IV and Bosona *et al*. (2011b), and a review of existing estimation tools. The emissions from the cases studies were first used to estimate emissions as g/kg food delivered and then calculations using the tools identified in the review were performed. The energy use was estimated as kWh/kg, first based on fuel consumption and energy content (SPBI, 2015) and then within the identified tools that offered energy estimations.

In the review, tools were identified and analysed with regard to their applicability for small-scale, local food producers based on criteria of estimated emissions (focus on emissions from the most common road vehicles), language, free online access and quick start. Desired, but not mandatory properties, were energy calculation and regional adaptation.

Table 3. *Details of distribution systems in the case studies in Paper V*

Area	Distribution	No. of routes	Vehicles	Total driving distance [km]	Total amount of food delivered [kg]
Roslagen	Producers-customers/collection points	4	3 cars, ≤ 3.5 tonnes	567	1 341
Uppsala	Factory (meat) retailers	10	5 trucks ≤ 20 tonnes	1597	17 499
Borlänge	Distribution centre customers	12	2 trucks ≤ 20 tonnes	486	42 402

The delivery system *Roslagslådan* provided locally produced, organic vegetables in boxes (8-10 kg) to customers in the Roslagen region (see Figure 4). The boxes were delivered to the subscribing customers (private homes, retailers and restaurants) once every second week during the season. The system is described in full in Bosona *et al*. (2011), Ljungberg *et al.* (2012) and Redman (2010). The distribution was managed by the producers using smaller vehicles, while a transport company was engaged for deliveries to the city of Stockholm. In Paper V, the estimations of emissions and energy use of the system focused on the distribution routes handled by the producers.

3.6.1 MODTRANS emissions model

The MODTRANS emissions model was used to estimate the emissions in Paper III. The model was developed by Gebresenbet and Oostra (1997) and uses recordings of speed, road slope and loaded weight as data input to compute vehicle fuel consumption. Emissions are then calculated based on emissions factors.

3.6.2 Emissions factors

Emissions estimated in Paper III by MODTRANS were carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbon (HC), nitrogen oxides (NO_X) and sulphur dioxide (SO_2). Emissions factors in the model originated from load classes from Demker *et al.* (1994) (see Table 4 Table *5*).

Table 4. *Emission factors, g/km (Demker et al., 1994)*

Load class	CO_2	CO	HC	NO_X	S
Lorry 52 tonnes	1300	3.9	1.3	25	0.70
Lorry 38 tonnes	1080	3.9	1.3	22	0.58
Lorry >18 tonnes	1040	5.0	1.5	19	0.60
Lorry 14 tonnes	750	4.5	1.5	14	0.41
Lorry 7 tonnes	460	2.8	1.1	5.9	0.26

Table 5. *Emission factors (g/tonnekm) (Demker et al., 1994).*

Load class	CO_2	CO	HC	NOx	Part.	S
Remote truck, 52 tonnes	76	0.23	0.08	1.5	0.10	0.041
Remote truck, 38 tonnes	83	0.30	0.10	1.7	0.13	0.045
Local truck, 14 tonnes	200	1.2	0.41	3.7	0.38	0.11

Emissions in the case studies (Papers II, IV and V) were CO_2, CO, HC, NO_X, particulate matter (PM) and SO_2, based on emission factors comprised the weighted values for mixed traffic, *i.e*. urban/rural (Trafikverket, 2009, 2010) (see Table 6). In Paper V, emissions were estimated with online tools for emission calculation as well.

The passenger car factors comprised weighted values for diesel and petrol cars, while the light and rigid trucks were all assumed to be diesel powered (see Figure 7). In Paper IV, heavy trucks were considered in all scenarios (see Figure 6). Light trucks were only considered in the routes from the local distribution centres (LDC) in scenario 4. For the vegetable box case in Paper V, car-specific factors from Transportstyrelsen (2010) or car model-specific factors from the UK Vehicle Certification Agency (VCA, 2009) were used, complemented with factors from Trafikverket (2009).

The emissions factors from the Swedish Transport Administration (Trafikverket) are based on a common model for vehicle emissions in the EU, *ARTEMIS Road Model*, and adapted to and tested for Swedish conditions (Sjödin *et al.*, 2009). The factors are also implemented in the NTMcalc emissions calculation tool (NTM, 2014).

Table 6. *Emissions factors used in Papers II, IV and V (Trafikverket, 2009, 2010)*

	CO_2 kg/km	CO g/km	HC g/km	NO_X g/km	PMm g/km	SO_2 g/km
Paper II: Weighted average, 2009 (Trafikverket, 2010)						
Passenger car (*Personbil*)	0.18	2.0	0.39	0.34	0.0053	0.0004
Light truck, diesel (*Lätt lastbil diesel*)	0.25	0.32	0.053	0.71	0.054	0.0004
Truck (*Lastbil utan släp*)	0.56	0.97	0.25	5.08	0.11	0.0008
Paper IV: Weighted average, prognosis for 2010 (Trafikverket, 2009)						
Heavy trucks (*Lastbil med släp*)	1.0	1.3	0.22	7.57	0.13	0.0015
Light trucks (*Lätt lastbil, diesel*)	0.27	0.30	0.050	0.67	0.048	0.00040
Paper V: Weighted average, 2008 (Trafikverket, 2009)						
Passenger car, petrol/diesel	0.19	2.2	0.42	0.36	0.0058	0.0005
Passenger car, E85	0.11	1.2	0.26	0.14	0.0028	0.0001
Passenger car, CNG	0.06	0.77	0.066	0.03	0.0028	0.00015
Passenger car, hybrid electric	0.10	1.28	0.26	0.034	0.0028	0.00027
Light trucks, diesel	0.27	0.34	0.057	0.76	0.062	0.0004
Truck	0.57	1.1	0.29	5.47	0.13	0.00083

3.6.3 Potentials for environmental impact

To provide insights into the environmental impact of the distribution systems, the acidification (AP), eutrophication (EP), human toxicity (HTP) and global warming (GWP) potential (see Table 7) were calculated from the estimated emissions amounts in Papers II and IV. Characterisation factors for the AP, EP, and HTP potential were selected from CML[14] 2001 (Swiss Centre for Life Cycle Inventories, 2007, 2010a). For global warming, GWP100 from IPCC 2007 (Swiss Centre for Life Cycle Inventories, 2007, 2010b) was applied. The Ecoinvent database v2.2 2010 was used for Paper II and v2.01 2007 for Paper IV.

Table 7. *Impact categories and emissions from the Ecoinvent database considered in Papers II and IV*

Potential impact	Emissions	Unit
Global warming potential (GWP100)*	CO_2, CO†	kg CO_2-eq
	CO_2, CO, HC, NO_X††	
Human toxicity potential (HTP)	NO_X, PM, SO_X	kg 1,4-DCB-eq**
Acidification potential (AP)	NO_X, SO_X	kg SO_2-eq
Eutrophication potential (EP)	NO_X	kg PO_4^{-3}-eq †, kg NO_X-eq††

*Potential impact over a time horizon of 100 years; **1,4-dichlorobenzene ($C_6H_4Cl_2$);
†Used in Paper II; ††Used in Paper IV

[14] Institute of Environmental Sciences (CML), Leiden University, Netherlands

4 Results

4.1 Distribution systems

4.1.1 The distribution and marketing channels of local food – Paper I

The questionnaire survey to identify characteristics of Swedish local food producers, their marketing channels and distribution systems (Paper I), revealed that the most commonly used marketing channels were farm shops, single retail outlets, restaurants and open markets (see Figure 8). The respondents' sales were mainly concentrated to their own municipality and their own county. The respondents were mainly microenterprises according to the EU definition (turnover <2 million Euro, fewer than 10 employees; EC, 2003).

About two-thirds of the respondents carried out the distribution themselves, mainly using smaller vehicles (passenger cars/small vans and light trucks/vans). The average producer delivered to 5-8 places, providing products 1-2 times per week. Maximum distance to a delivery point was on average about 170 km and median distance 70-85 km.

Transport and marketing were ranked as the largest impediments to business development (see Figure 9) and the main causes of impediments were authorities/regulations and lack of finances. Transport-related problems were mainly perceived to be caused by small volumes and long cumulative distance/time-consuming transport. Marketing was the most common area of cooperation used between producers, followed by distribution, labelling, production and processing. Many producers saw no disadvantages, only advantages, with their cooperation. Many producers had no cooperation with other producers.

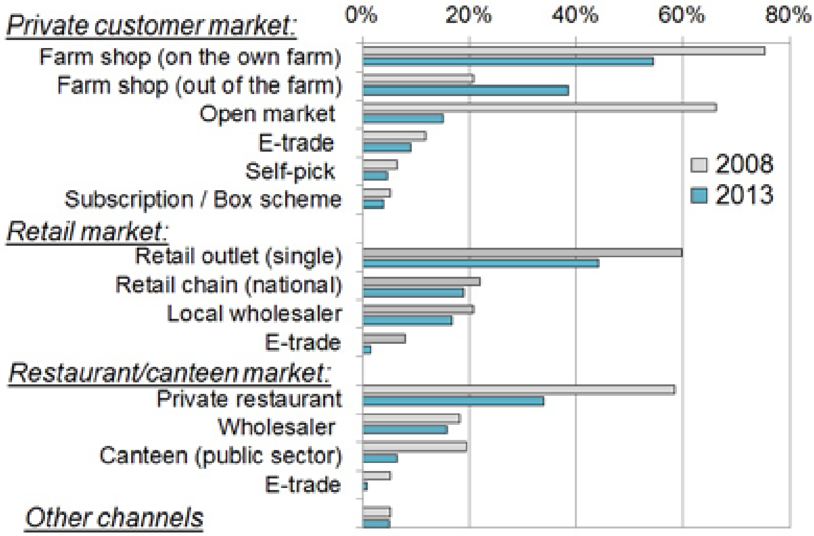

Figure 8. Marketing channels used, as percentage of respondents in the survey 2008 and 2013 (selection of multiple options was possible).

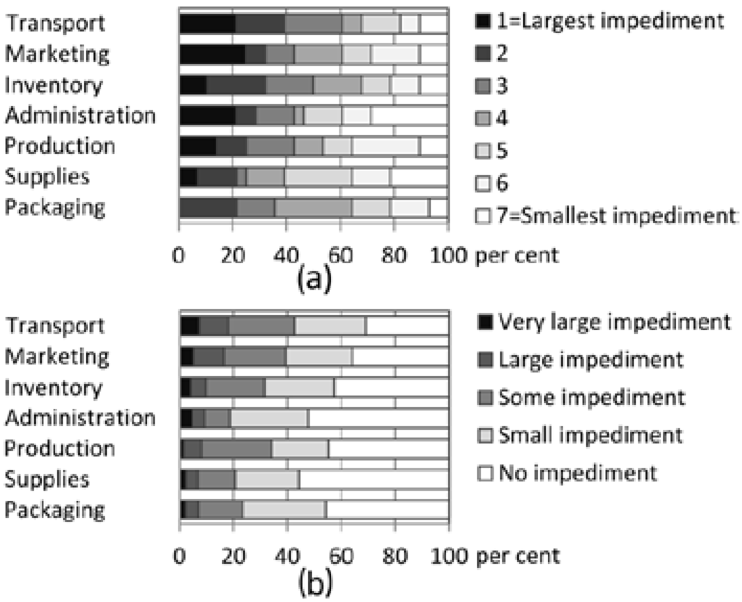

Figure 9. Producer ranking of experienced impediments to company development in production areas in the part-surveys a) S1 (n=28) and b) S2 (n=188).

4.1.2 A closer look at the distribution systems – Papers II-V

This section describes the networks and cooperation between participants in the studies (Papers II-V), including the situation after the demonstration. The participants in the studies were part of distribution systems of different scales and with different organisations (see Table 2). Table 8 presents an overview of distances and route lengths in the four systems.

Table 8. *Delivery distances for local food producers (radius data for Halland, Dalarna and Roslagen taken from Bosona, 2013)*

Area	Paper	Maximum radius from producer to CC [km]	Maximum radius from DC to delivery point [km]	Number of routes	Route length [km]				
					Min	Max	Mean	Median	SD
Halland	II[a]	50	480	-	-	-	-	-	-
Uppsala	III, V	100[b]		38	2	391	106	53	104
Dalarna	IV, V	330	50	12[c]	16	58	41	46	16
Roslagen	V	30	115	5	94	190	140	131	41

[a]Most (96%) customers were within 180 km radius in the initial scenario.
[b]Maximum radius from producers to delivery points.
[c]Routes in and around Borlänge city.

4.1.3 Distribution in cooperation with integration in a large-scale food supply chain, Halland county – Paper II

The producers in this case were concentrated in the county of Halland, with nearly all the main customers in the same or adjacent counties. The producers offered a wide range of products such as fruit and vegetables, meat, egg, grain and bread, dairy and other products. The producers mainly handled the distribution themselves or used transport companies. The load rate when shipments left the producers in Halland was over 50% in most cases. The ambition among the producers was primarily to increase sales and improve the logistics solution. Compared with a national study (Paper I), the Halland producers had higher mean turnover and transport costs (as a percentage of total costs) were slightly lower among the Halland producers.

The use of the electronic trading system resulted in direct savings of 15-20 Swedish kronor (SEK) per invoice (but working time savings not included). Licence costs (6300 SEK/year) were free during the first year and the cost of IT support was included from the first year.

Initial transport costs (based on questionnaire answers from four producers) were 268 SEK per hour. With the new system, costs for collection (80 SEK/occasion) and fees for transporting boxes (54 SEK), pallets (232 SEK) or freezer boxes (414 SEK) were estimated. Costs for packaging and warehousing in a future system were not determined during the pilot project, nor were the costs of using the specially designed return boxes.

The producers tried the system with the electronic trading place and the distribution system. Although it worked, it never became more than a trial. The producers found using the electronic trading place complicated, the retail chain lost some of its interest and the producer network developed differently.

The producers wanted to expand to a larger market and sell to customers outside the county and also outside Sweden. In their case, they acted more as food producers from a certain region when distance to customers increases, rather than as local food producers.

In the system currently in place, equipment (such as scales and packaging machines) for value-adding activities is available for producers at the collection centre (CC). The company that manages the CC acts as a central point, handling customer orders and invoicing, while all distribution is now managed via customers' wholesalers.

4.1.4 Distribution in and around Uppsala city – Paper III

Paper III describes the attempt to create new distribution solutions in and around Uppsala by involving the participants (in regular seminars), and analysing and discussing the results. The distribution took place within a radius of approximately 100 km from Uppsala. Eight companies participated in the field studies and 38 routes were observed. Routes were planned by drivers and were mainly in the order of priority: shops, restaurants and schools or nurseries. Queuing at delivery points and lower load rates were more common in urban areas than in rural areas. Several routes had similar delivery points and covered similar areas to the routes used by the other companies. It was concluded that the possibilities of cooperation on a local scale were very good (see section 4.2 Optimisation within the distribution systems).

In the seminars, participants expressed satisfaction with the results of the optimisation analysis and were interested in continuing the process. However, the participating companies did not complete the proposed horizontal cooperation. One reason for this was the difficulty of agreeing on the signage on vehicles. This signage was seen as an important marketing channel and agreement on new signage was associated with negotiations and additional costs.

The project on city logistics in Uppsala's city centre followed in 1999-2001 (Ljungberg, Gebresenbet & Eriksson, 2002; Ljungberg & Gebresenbet, 2004), where possibilities to coordinate private companies' deliveries to the city centre were pursued. Furthermore, the municipality arranged municipal transport (non-food goods) in the ways discussed in the seminars. Uppsala municipality's "Sustainable goods transport" started in 2008 (Åhlman, 2009).

4.1.5 Municipal distribution in Dalarna county – Paper IV

In the Dalarna study (Paper IV) a coordinated distribution network was in place at the beginning of the study. Eleven producers delivered food to the joint municipal DC located in Borlänge. The total quantity delivered per year was around 2761 tonnes. The producers were located 7-415 km from the DC. The four municipalities in cooperation used the local transport company and its DC for food transport to 149 municipal units. The majority of these units, around 60%, were located in Borlänge municipality. The units often received food deliveries 1-2 times per week. Deliveries took place on Monday-Friday in Borlänge, Monday and Wednesday-Friday in Gagnef and Tuesday and Thursday in Säter and Smedjebacken.

Some deliveries were made before the schools opened for the day. In these cases, the drivers had access to storage rooms and there was no need for staff to be there to receive the goods. This practice improved traffic around schools and resulted in fewer interruptions for the school staff.

The municipalities in Dalarna have made efforts to increase the number of local producers in their network. The municipalities are continuing to work on simplification so that smaller producers can bid in the tendering process, *e.g.* through procurements to supply in smaller amounts. The other two nearby municipalities have expressed interest in joining the cooperation at some point in the future.

4.1.6 Distribution of vegetable boxes – Paper V

The delivery system of *Roslagslådan* was up and running for some years, but is currently paused, and only one of the producers has continued with home deliveries.

4.2 Optimisation within the distribution system

4.2.1 Route optimisation in and around a city – Paper III

The 38 routes in Paper III were optimised as single routes and as multiple routes. The driving distances and times were reduced by 10% on average on individual routes. When comparing the observed routes with optimisation results, it was found that six of the 38 routes studied were already planned optimally. Motor idling occurred on 66% of the routes, in some cases due to queues at delivery points and without idling being required.

The optimisation for individual routes showed potential for reducing the distance travelled by 6% in total for company A, 25% for company B, 7% for companies C and D, 16% for company E, 12% for company G and under 2% for companies F and H. These reductions are presented in more detail in Table 3 in Paper III. The maximum distance reduction on a single route was 34%, and the maximum time reduction was 40%. Total optimisation of all routes reduced the distance travelled by 35% (1408 km) and the number of routes by 58%.

Several routes with overlapping service areas were identified and possibilities for coordinating these routes were examined. Combining 2-3 routes in certain areas around the city resulted in potential reductions in transport distances of 25-46% (94-352 km) and in time of 23-42% (1:55-5:58 hours and minutes). For further details, see Table 5 in Paper III.

There were good opportunities for combining routes for similar goods, *e.g.* bread from different suppliers, without any structural changes to the system. The producers were located near each other geographically and had customers in similar areas. On some routes there was considerable queuing and trucks were even following one other from one delivery point to the next.

The load rates were found to be higher in the companies that distributed in rural areas rather than in urban areas (see Figure 10). There were correlations between unloading time and weight, volume and number of packages at many companies, but not all (see Table 9).

4.2.2 Optimisation of municipal distribution – Paper IV

In Paper IV, route optimisation was first performed on 12 routes in Borlänge for distribution from the DC to the municipal units, based on the delivery orders of actual routes. Optimisation of individual routes resulted in reductions in transport distances of up to 48%. For seven routes (nos. 2, 4-8 and 12 in Figure 11), the reduction was 14-28 km. Reductions of 5 km or less were found for four routes (nos. 1, 3, 10 and 11). For one route (no. 9), there was no difference between the optimised and non-optimised route.

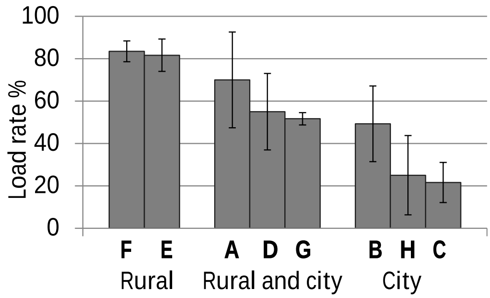

Figure 10. Load rates (bars show standard deviation) on routes of companies A-H.

Table 9. *Summary of unloading times and correlations with three load variables*

Company (no. of delivery stops)	Unloading time [min:sec]			Correlation coefficient between unloading time and:		
	Mean	Minimum	Maximum	No. of packages	Volume	Weight
A (99)	07:51	01:05	34:04	0.46	0.60	0.61
B (61)	03:35	00:27	19:42	0.55	n.s.	0.56
C (93)	01:40	00:20	04:55	0.58	0.63	0.59
D (42)	07:04	01:08	33:18	0.58	0.48	n.s.
F (19)	06:23	01:51	16:54	0.54	0.63	n.s.
G (29)	06:41	01:44	22:22	n.s.	0.46	0.55
H (12)	07:08	03:04	11:12	n.s.	n.s.	n.s.

n.s.: Correlation not significant, p>0.05.

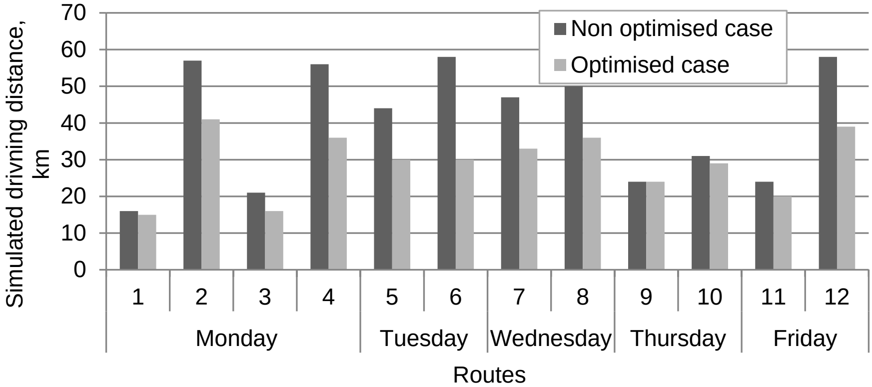

Figure 11. Simulated driving distances for routes in Borlänge.

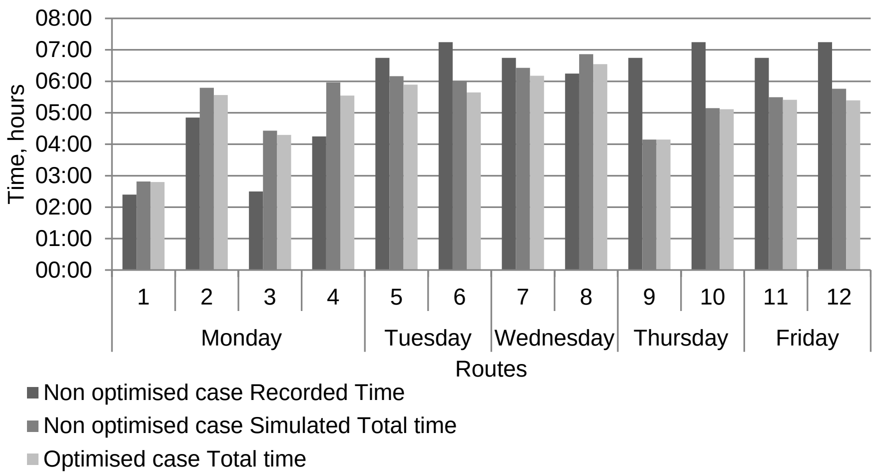

Figure 12. Simulated driving times for routes in Borlänge.

The distances and travel times were reduced on average by 28%. The total time, taking service times[15] into account, was reduced on average by 4%. On most of the routes (8 out of 12), the differences between reported and simulated times for the non-optimised case were ≤ 20%. However, on some routes (nos. 3, 4, 9 and 10 in Figure 12) derived from the simulated results based on the delivery lists, the driving times specified in the given timetables were 1-2.5 hours longer or shorter.

The entire delivery system was analysed using the four scenarios illustrated in Figure 6, which were based on the amount of food ordered from the producers to the municipal units in the four municipalities, together with the location of producers, distribution centre and municipal units. In scenario 1, which was used as a reference, all producers were assumed to undertake their own transport for 25 routes, 334 visits, 7627 km and taking 228 hours. Compared with scenario 1, the distances in scenario 2 (options I and II), scenario 3 and 4 were reduced by 64, 68, 74 and 74 %, respectively. The time improvements were 54, 60, 63 and 58 %, respectively, the number of routes was reduced by 36, 44, 64 and 40 %, respectively (to 9-16 routes), and the number of visits was more than halved (to 158 visits).

The second scenario, option II, was most similar to the real situation in Dalarna and this would imply that a change to scenarios 3 or 4 could reduce the distances by 16-17%. Scenario 3 took 7% less time than scenario 2, option II, while scenario 4 took 5% longer due to extra unloading and loading time at LDCs.

There were delivery time windows, set by the municipal units, in the existing system. All deliveries were scheduled during the day (6:00-18:00) and the most popular time window was 6:00-8:00. In the analysis, delivery time windows were made more flexible during the day, allowing delivery at any time between 6:00 and 18:00. The flexible delivery time windows reduced the driving distance by 62% (from 1457 to 552 km) and the time by 23% (from 78 to 60 hours).

Location analyses were carried out to identify the most suitable location for a DC for a local distribution system. The centre-of-gravity technique generated three new possible locations based on data on: i) producers and delivery points, ii) producers and iii) delivery points. In further analyses, using the load-distance technique and location factor rating method, the existing location was identified as the most preferable of the three candidates (see Figure 13).

[15]Service times in the simulated routes consisted of 30 minutes loading time for each route, 15 minutes per delivery stop for unloading and handing over the goods, and 1.5 hour for resting and extra time.

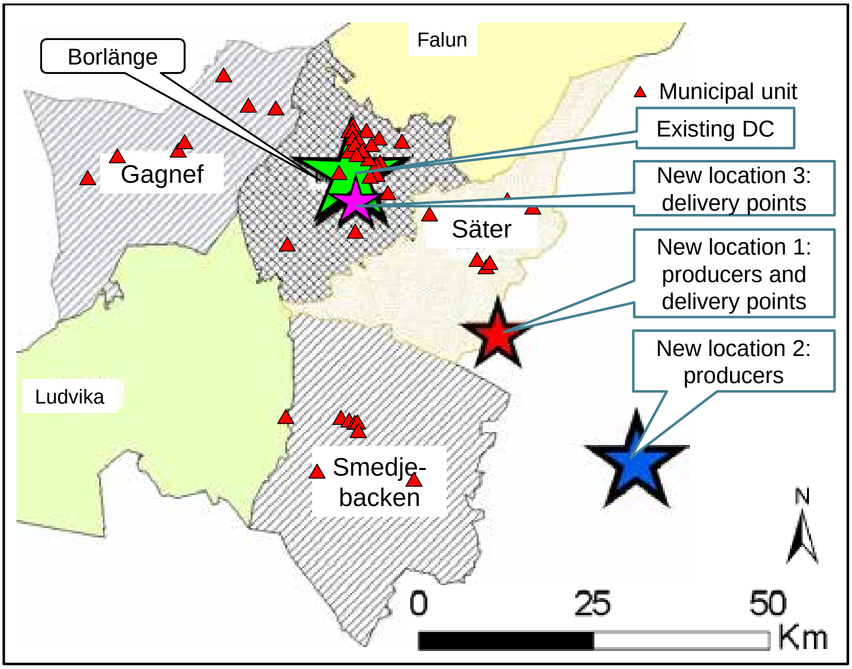

Figure 13. Results of centre-of-gravity technique to identify the most suitable location for a distribution centre (DC) for a local distribution system. The locations are based on data on producers and/or delivery points.

4.3 Estimating vehicle emissions and their effect on the environment

4.3.1 Distribution in cooperation with integration in a large-scale food supply chain, Halland county – Paper II

Estimated emissions in the four scenarios in the integrated distribution system in Halland are shown in Table 10. The emissions reductions (except for NO_X) were 5-86% and 16-92%, respectively, compared with the reference scenario 1, case A and B. Scenario 3 option II had the lowest emissions (66-86% and 79-92% lower than in case A and B, respectively) except for NO_X, which was only reduced by 48% and 37% in relation to case A and B, respectively. Scenario 4 had the lowest NO_X emissions (62% and 54% lower than in case A and B, respectively). The low NO_X values in scenario 4 made this scenario that with the lowest potential for environmental impact for AP, EP and HTP, while the lowest GWP potential was achieved in scenario 3 option II (see Figure 14).

Table 10. *Distances and estimated emissions in the scenarios for Halland. Scenario 1 acted as the reference scenario*

	Distance [km]	CO_2 [kg]	CO [g]	HC [g]	NO_X [g]	PM [g]	SO_2 [g]
Scenario 1, case A*	6159	1540	1971	326	4373	333	2.5
Scenario 1, case B*	6159	1396	5420	1018	3613	233	2.5
Scenario 2, option I	3774	931	1498	258	2615	195	1.5
option II (excl. LSFDC)†	727	407	705	182	3692	80	0.58
option II (incl. LSFDC)‡	1641	577	1228	279	4144	111	0.87
Scenario 3, option I	3493	873	1118	185	2480	189	1.4
option II (excl. LSFDC)†	446	250	433	111	2265	49	0.36
option II (incl. LSFDC)‡	1360	361	575	135	2582	73	0.54
Scenario 4	2343	586	750	124	1663	127	0.94

*Case A: light trucks only. Case B: light trucks and passenger cars

†The transport from the DC to the delivery points was excluded.

‡The transport from DC to delivery point was considered to be integrated in the large-scale food distribution channel (LSFDC), accounting for up to 30% of vehicle load.

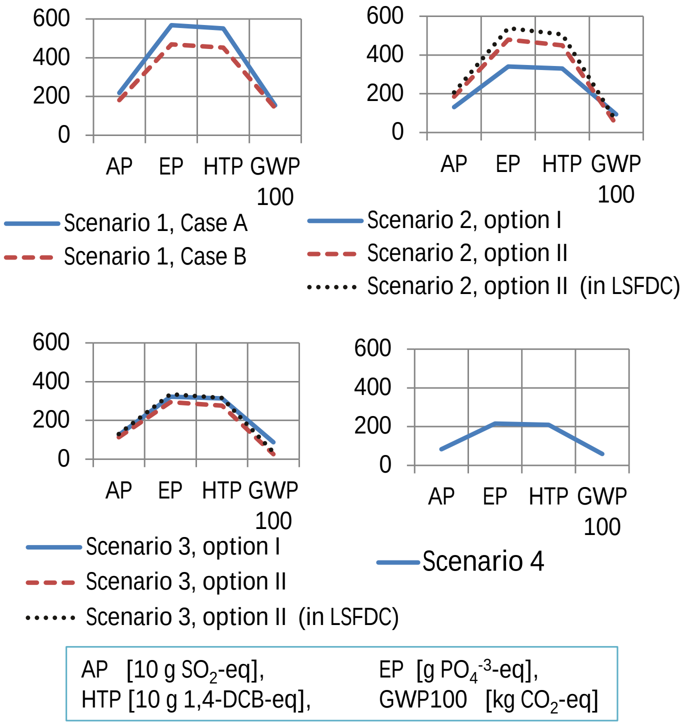

Figure 14. Summary of estimated environmental impacts in scenarios in Halland, Paper II. Option II excludes distribution from the distribution centre (DC) to delivery points. Option II (in the large-scale food distribution channel, LSFDC) includes 30% of the emissions from the LSFDC from DC to delivery points.

4.3.2 Distribution in and around Uppsala city – Paper III

Estimated emissions in each of the eight companies in the study in and around Uppsala are presented in Table 11. Optimising all the routes together reduced the emissions by 48-50%. On several (66%) of the routes, motor idling occurred during unloading. In some cases motor idling at delivery points can be required to control the temperature in the loading zone. However, this was not the case on many of the routes that had a higher percentage of motor idling time.

Queuing, which was common at some delivery points in the city centre, and motor idling contributed to increased emissions. An example with two companies (A, mainly delivering in rural areas, and C, mainly in the urban areas) showed that company C had higher emissions per kilometre even though its vehicle fuel consumption was lower than company A's. Motor idling was more common in company C.

Table 11. *Summary of emissions in kg for companies A-H in Uppsala and for total route optimisation, Paper III. The emissions were calculated using the* MODTRANS *model based on route observations*

Company, produce	Distance	Emissions [kg]				
		CO_2	CO	NO_X	HC	SO_2
A, meat	1254	489	1.51	9.78	1.13	0.007
B, bread	163	79.5	0.25	1.59	0.19	0.0009
C, bread	310	227	0.70	4.54	0.53	0.003
D, bread	235	45.8	0.14	0.92	0.11	0.0007
E, bread	956	186	0.57	3.73	0.43	0.003
F, flowers *etc.*	245	68.0	0.21	1.36	0.16	0.0009
G, frozen food	538	105	0.32	2.10	0.24	0.002
H, meat	343	89.2	0.28	1.78	0.21	0.002
Total	4044	1290	3.98	25.8	3.00	0.02
Total after opt.	2636	671	2.07	13.4	1.56	0.01

4.3.3 Municipal distribution in Dalarna county – Paper IV

In Paper IV, the impact assessment performed for the four scenarios in the integrated municipal distribution resulted in lowest in emissions and environmental impacts in scenario 4. The estimated emissions, on which the environmental impact potentials were based, are presented in Table 12. The environmental impacts reduction was 64, 68, 73-74 and 75% for scenarios 2 (option I), 2 (option II), 3 and 4, respectively, compared with scenario 1 (see Figure 15).

Table 12. *Distance and estimated emissions in the scenarios in Dalarna, Paper IV. Scenario 1 was used as the reference scenario*

	Distance [km]	CO_2 [kg]	CO [g]	HC [g]	NO_X [g]	PM [g]	SO2 [g]
Scenario1	7627	4347	6864	1678	36381	763	6
Scenario2, option I*	2734	1558	2461	601	13041	273	2
option II*	2417	1378	2175	532	11529	242	2
Scenario3	2022	1153	1820	445	9645	202	2
Scenario4	2015	1099	1715	415	8939	193	2

*In option I all producers were assumed to deliver to the distribution centre (DC) themselves, while in option II the deliveries to DC were partly correlated.

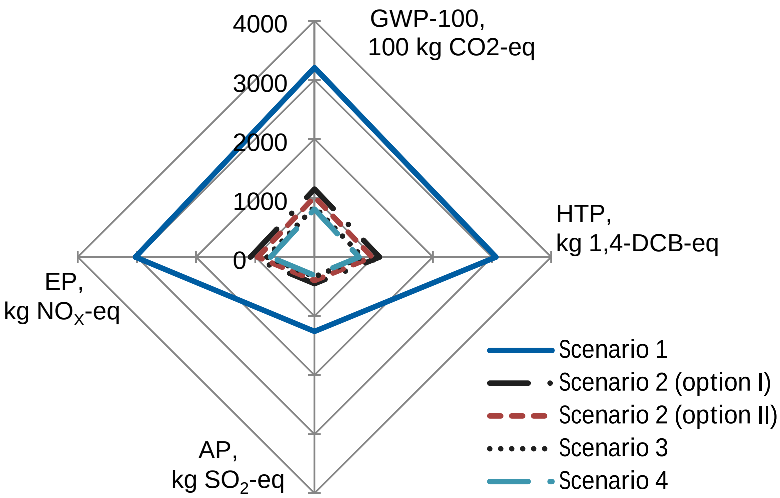

Figure 15. Summary of the estimated environmental impacts of different distribution scenarios, Paper IV.

4.4 Quantifying emissions and energy use in local food distribution – Paper V

The emissions were in general highest in the smallest distribution system, the Roslagen vegetable box case, except for the NO_X emissions (see Table 13). The energy use was highest in the Roslagen case and lowest in the Borlänge case (see Table 14). The energy use in Uppsala and the Roslagen case were similar to that reported for vegetable transport to a farmers' market (Wallgren, 2006). In the vegetable box case, the energy use was seven times lower in the external route in the large-scale distribution by the transport company than in the routes managed by the producers.

Optimisation of single routes reduced driving distance and emissions by 10-76%. Shifting to alternative fuel could reduce the amounts further. The emissions estimations, with several types of fuel and vehicles, revealed large variation, especially for CO_2 and NO_X. The diesel and petrol vehicles gave the highest emission amounts.

Seven tools were identified that could be of use to food producers for estimating energy and emissions from their transports. These tools included emissions factor tables (Trafikverket, 2015), website tools (EcoTransIT, 2015; Scania, 2015; Volvo, 2015), spreadsheet models (UNEP, 2015), and vehicle databases (Transportstyrelsen, 2015; VCA, 2015). However, only three (EcoTransIT, 2015; Scania, 2015; Volvo, 2015) reported energy consumption.

Table 13. *Results obtained for estimated emissions from distribution in the three case studies*

Area of case study	Emissions [g/kg]					
	CO_2	CO	NO_X	HC	PM	SO_2/SO_X
Roslagen case	93	0.21	0.15[a]		0.0056	0.00016
Estimation tools	80-893	0.23-4.6	0.0016*-0.59	0.049-0.20[d]	0.012-0.030[c]	0.00013[e]-0.00032
Uppsala case	32	0.098	0.64	0.00046	-	0.074
Estimation tools	0.035-87[g]	0.11-1.0	0.00037-1.8	1.8×10^{-5}[b]-0.21[d]	1.2×10^{-5}[c]-0.11[c]	2.4×10^{-7}-0.00017[e]
Borlänge case	6.4	0.014	0.052	0.0025	0.00099	9.2×10^{-6}
Estimation tools	0.0041-13[g]	0.014-0.058	2.8×10^{-5}-0.10	1.1×10^{-6}[b]-0.017[d]	5.8×10^{-7}[c]-0.0066[c]	2.6×10^{-8}-2.2×10^{-5}[e]

[a]NO_X+HC
[b]Non-methane hydrocarbon (NMHC)
[c]PM 10
[d]Volatile organic compound (VOC)
[e]SO_X
[f]Non-methane volatile organic compound (NMVOC)
[g]Carbon dioxide equivalent (CO_2e)
*Values for one route (109 km, 171 kg) with one of the vehicles

Table 14. *Summary of estimated energy use in distribution in the small-scale food supply chains in the three case studies*

	Energy use [kWh/kg]								
	SPBI, 2015						EcoTransIT, 2015	Scania, 2015	Volvo, 2015
Case	Total	Min	Max	Mean	Median	SD	Total	Total	Total
Roslagen	0.34	0.23	0.85	0.45	0.37	0.29	-	-	-
Uppsala	0.25	0.07	0.44	0.25	0.24	0.13	0.14	0.018	0.30
Borlänge	0.040	0.019	0.071	0.040	0.036	0.016	0.016	0.038	0.050

5 Discussion

In this thesis, distribution systems for food from local and small-scale producers were analysed. The different scales of the systems studied enabled a broader view to be obtained of the situation for local food producers in Sweden. Relatively few studies so far have examined this sector and there are limited data available. Since the situation for producers operating on a small and/or local scale can vary considerably due to parameters such as location, competition and hardiness zone, it proved useful to study differing systems rather than comparing several very similar systems. Challenges in the distribution of local food relate to fulfilling customers' expectations and managing the distribution, despite lack of finances, time, knowledge and without the economies of scale of larger companies.

The question of whether local food producers can meet the high expectations of consumers is not easily solved and may not have a definitive answer. However, maintaining transparency will make it easier for consumers to check whether their specific expectations are fulfilled. Traceability is of special value for local food and it also contributes to the transparency.

In view of the lack of a general definition of local food (Jones, Comfort & Hillier, 2004; Hallberg & Granvik, 2013), it is difficult to clearly identify and analyse local food systems. The producers participating in the questionnaire study in Paper I indirectly indicated what they mean by local when answering the questionnaire. The sales of those producers were mainly concentrated to their own municipality and their own county, with a mean maximum delivery distance of barely 170 km. For the case in Halland described in Paper II, their food can be seen as local food when it is sold in Halland and adjacent counties (since Halland is a very small county), but when sold in another part of Sweden or abroad it is rather to be considered as "regional food", food from a specified region.

Just because food has travelled a short distance to the customer does not mean that it is automatically better from an environmental point of view, as pointed out by Wallgren (2006), Ilbery and Maye (2005) and others. However, traceability and emotional connections are likely to be greater when customers buy from nearby producers. Transparency in production can also be higher if customers know the area of production and the producers. This can be used as an advantage for local food when competing with food produced in systems on a global scale. However, there is still room for improvement in transparency concerning the environmental impact and pricing for local food.

The case studies in this thesis revealed that there is potential for local small-scale food producers to improve their distribution. Cooperation, integration and route optimisation are suitable strategies for producers to make their transport more efficient and reduce their environmental impact.

For sustainability in supply chains, it is important to optimise the whole chain rather than sub-optimising parts of it. The studies in this thesis mainly focused on cooperative and integrated distribution in the local food supply chain, trying to optimise distribution for several companies in the chain. Due to the fragmented and often inefficient distribution infrastructure in this kind of supply chain (Gebresenbet & Bosona, 2012), this is a relevant area for research.

5.1 Collection of data

Collecting data through the use of questionnaires is challenging, especially in a group such as local food producers, who feel that they are frequently subjected to surveys and that the results are seldom of any direct use to them. A response rate of 20% through email contact alone, as in the second sub-survey (S2) in Paper I, should be considered good in this case.

Route planning and optimisation may be powerful tools, but they can only be used if the distribution systems can be described sufficiently well. In the work described in this thesis, it was often difficult to obtain information about the complete system, *e.g.* when the transport contained more products than those covered in the study or when the companies responsible for the transport were not willing to share information. This seems to be due to reasons such as limited resources for finding the requested data, lack of interest and a desire to protect their own interests and those of clients. Transport systems are inherently location-specific and depending on the organisation of the distribution system, different data collection methods need to be used.

This work of identifying and evaluating different distribution systems enabled us to recognise and support changes that could work more effectively towards achieving a sustainable food system, which is in line with Bloom and Hinrichs (2010).

The choice of methods used for mapping out local food producers depended greatly on data requirements and availability in the systems. In Dalarna (Paper IV), delivery/purchase data were available from the municipalities and producers, reducing the need to make direct observations on routes. In Halland (Paper II), a questionnaire survey with complementary interviews was found to be an appropriate method to gather information. In Uppsala (Paper III), direct observations yielded detailed primary data and was the data collection method that worked best for mapping the system. The main advantage of the direct observation method used in Paper III was the detailed results available from the route observations. Primary data collection together with interviews and seminars enabled insights into the distribution of multiple companies.

Secondary data were collected in the studies in Halland and Dalarna (Papers II and IV). In Paper II there were no empirical data available initially, so questionnaires and interviews were used. This method can be applied at a distance, but includes additional difficulties in understanding the reliability of the data. The summary of orders and public procurements in the Dalarna study (Paper IV) gave detailed information on addresses and amounts ordered. Although detailed route information from the transport company was difficult to access, the summary from the municipalities together with interviews with producers allowed a fairly good understanding of the distribution system. A great advantage with the data obtained from municipalities was that it covered all their units. This would have been difficult to record manually, since it is a time-consuming data collection method.

Comparing the data from the municipalities with the route simulations in Paper IV gave different results in driving time in some cases. It was unclear whether this was due to the road model, the assumptions, the data material or something else. This is one problem when using customer/producer-specified data instead of recording the data directly.

The data for the calculations in Paper V were taken from published and unpublished material from the case studies. Since the aim of the calculations was to estimate energy and emissions in relation to the weight of food delivered, the selection of case studies included only studies with sufficiently detailed data about the length of routes, weights of goods and types of vehicles. Lack of sufficient data on weights prevented estimations of emissions and energy use in the case of Halland (Paper II).

5.2 Cooperation, integration and competition

Cooperation between producers can open possibilities for reducing cost and improving service in the same way as Christopher (1998) argued that it is more important for partners in a supply chain to cooperate for the most competitive supply chain than to compete for individual company profits. In fact, local food producers in a region can often be seen as partners in the same supply chain, where cooperation with nearby producers can give competitive advantages for regional products and supply chains over conventional products or products from other regions. Still it can be difficult to realise when cooperation is beneficial and when common goals can be achieved. The most common areas of cooperation among local food producers included marketing and transport (Paper I). At the same time, these are the areas regarded by producers as the largest impediments to business development. This, together with the finding that many of the producers wanted more cooperation and that many had no cooperation with other producers, highlights the benefits, difficulties and possible potential in marketing and transport cooperation. The main reasons cited for not cooperating were lack of suitable partners and lack of distribution systems where time and cost benefits could be achieved.

Increased centralisation among larger retail chains can make it more difficult for smaller producers to benefit from and become integrated into these chains. However, as the case studies in this thesis showed, integration is still possible. More suitable distribution channels for these producers can be found on a local and regional scale, *e.g.* wholesalers, municipalities and local markets.

The case studies showed that there was potential for making distribution more efficient. The results from the studies were encouraging and identified several improvements, but subsequently the projects developed in different directions.

With the Uppsala study (Paper III), the participating companies did not complete the proposed cooperation, despite good cooperation possibilities. Except for the stated difficulties of agreeing on the signage on vehicles, competition may also have prevented the companies from seeing the benefits of cooperation or they might have needed more proof of positive effects from the cooperation. It may have been the case that the companies did not see each other as being closely connected, and focused instead on developing stronger vertical relations along their own supply chains. They may also have needed more help after the project to build up and develop their cooperation further. The study led to further studies and a pilot demonstration of city logistics (Ljungberg *et al*., 2002; Ljungberg & Gebresenbet, 2004). More recently, municipal coordination of non-food goods has been initiated (Åhlman, 2009).

In the Halland study (Paper II), the producers continued to cooperate, although not in the intended, IT-integrated, form. The fact that they were a group of producers working together was advantageous, since they could offer customers a more reliable supply and a wider range of products.

Retail chains and municipalities have noted the consumer interest in local food. Locally produced food can *e.g.* serve as premium products in shops or increase the traceability and, hopefully, the quality of food served in the municipality. The municipalities in the Dalarna study (Paper IV) want to have a high number of local producers supplying their municipal units and have been working to ease the procurement process for small-scale producers. At the same time, however, the municipalities have to comply with the public procurement directives[16] where a specific location of origin cannot be required. One way of encouraging local producers (who are often small-scale and with seasonal production) was practiced in Dalarna, where producers were invited to make tender on supply of smaller quantities or supply during part of the year. By taking control of the local distribution system, the municipalities shifted from using national distribution systems to having a more local and transparent distribution system.

5.3 Route analysis and optimisation

In the studies in this thesis, the optimisation of routes proved to be a useful method for identifying, improving and evaluating distribution systems. It proved possible to reduce transport distances, time and the number of routes with optimisation. Potential savings were identified when optimising individual and multiple routes. Multiple routes having the greatest potential can require both cooperation and integration.

Simulations and demonstration trials of coordinated transport led to fewer delivery stops, which may result in less queuing and motor idling with associated costs and emissions. Furthermore, traffic safety can be improved with fewer stops required, *e.g.* at schools.

The use of external logistics service providers can have many advantages for the small-scale producers, allowing them to concentrate on their area of competence. The producers in Paper II dropped their own transport fleet because they found the use of wholesalers' transport to be a better solution, reducing the need to have their own vehicles and providing opportunities for expanding their distribution area.

There are many ways of optimising distribution systems, but of central importance is using the vehicles as efficiently as possible in order to reduce 'empty miles' with a low or zero load rate. It is also a matter of using the

[16] Lag (2007:1091) om offentlig upphandling (SFS 2007:1091) [Swedish Public Procurement Act]. Stockholm: Socialdepartementet. http://rixlex.riksdagen.se [2012-09-13]

‘right’ vehicle for the right purpose. This must be done in ways that maintain the efficiency of the system and without a unilateral focus on load rates. In the Uppsala distribution system (Paper III), load rates were lowest in the urban areas. When looking at the individual companies, this problem seemed to be solved by using smaller vehicles for some urban routes. However, when looking at several companies at once, the potential of coordinating the distribution became clear. The problem in agreeing on cooperation and coordination also became clear in the project.

The relationship between unloading time and the amount of goods unloaded was analysed for the routes in Paper III and revealed large variations in unloading times. From this analysis, significant correlations were identified, but a large part of the variations could not be explained by these correlations and for some routes the correlations were very weak or insignificant. These results are well in line with *e.g.* Ljungberg & Gebresenbet (2004) and Allen *et al.* (2000) in terms of wide ranges observed in average duration of deliveries to retail shops in urban areas.

In general, it is still difficult to predict the unloading time, since it is influenced by a number of factors. Examples of factors that can cause delays on reaching the delivery area are the design of the delivery areas, whether receiving personnel are required and the availability of equipment for unloading. Some of these factors will influence the duration of each delivery stop rather than the time required per goods item. Fewer delivery stops, which could be the result of route optimisation and coordination of deliveries, could therefore reduce the variation in unloading time. Route optimisation could improve distribution considerably by reducing driving time, but it is also important to have unloading areas that are well suited to the purpose, as this can also shorten the time required and facilitate unloading activities.

Better knowledge on how different factors influence the unloading time would increase the possibilities to predict delivery times. This would improve the reliability of the planning model and possibly increase the acceptance for the proposed delivery time windows. The research presented in this thesis makes a contribution to the limited existing knowledge, but more research is needed in the area.

There is also uncertainty in the prediction of travel times. As indicated in Paper IV, this uncertainty may be of similar magnitude to the potential savings when analysing individual routes. Therefore, the proposed solutions should always be manually assessed or evaluated. However, when multiple routes were optimised in the case studies, the magnitude of potential savings was so great that the uncertainty in predictions for individual routes could almost be neglected.

The scenarios in the optimisation analyses were designed to allow solutions within a study to be compared, *i.e*. the focus was on comparing scenarios within the studies, rather than comparing studies or separate systems. With quantification of emissions and energy use, as in Paper V, it was also possible to start comparing different systems.

Changes in delivery time windows can have a large impact and offer more efficient distribution. Although delivery time windows are often set for good reasons (*e.g.* when staff are available to receive the goods), their impact on the results is so great that they should always be challenged. There may be alternative solutions. In the case in Dalarna (Paper IV), it was confirmed that significant improvements could be gained by amending the delivery time window and this was achievable since there is a high level of trust between the partners in the distribution network. When suggesting changes in delivery times, it is not necessary to have flexible delivery times throughout the day to achieve more efficient distribution. Deliveries during non-office times (evenings/nights/early mornings) can also be possible in some distribution systems.

The current DC in Dalarna (Paper IV) was well situated according to the location analysis. However, it should be recognised that a location analysis based on an existing system, such as that in Paper IV, is valid only as long as the system is not changed. The most suitable location can change when the system expands or alters in other ways. For the situation in Dalarna, Borlänge is the municipality with the highest number of deliveries and with only small changes in the system it is likely that the location will continue to be a suitable site. Since two neighbouring municipalities, Ludvika and Falun, are interested in joining the system, it is possible that the system will change within a few years. In that case, Borlänge will still be in the middle of the system and will probably remain a good site for a DC.

5.4 Estimating emissions and environmental impacts

The estimated amounts of emissions were closely connected to driving distance, vehicle and fuel. The ambition in the presentation of emissions and environmental impacts was to give a broad perspective, illustrating the diversity of consequences of the emissions from the distribution. Both improved logistics and environmental sustainability were the focus in the case studies (Papers II-IV). The preservation of quality, which should also be included in proper design of food supply chains (Vorst, Tromp & Zee, 2009), was considered, but not in depth.

The distances the food was transported, the 'food miles', were used in this work within the estimates of the efficiency in the distribution system rather than as the final measurement (as recommended by *e.g*. Coley, Howard & Winter, 2011; Johard *et al*., 2012). Carbon dioxide was reported, as well as other emissions, to cover more than global warming, *e.g*. acidification, eutrophication and toxicity for humans.

Emission amounts were used to illustrate the environmental impacts in Papers II-V. In Papers II and III, different scenarios for a certain part of the distribution chain were examined and analysed based on impact categories. No impact estimation was made in Paper V, since it evaluated different distribution chains rather than different scenarios of one chain. This was to maintain good transparency in the estimations and make it easier to add other parts of the distribution or supply chain later on.

The profile visualisation of the estimated environmental impacts in Papers II and IV gave an additional perspective to the comparison of scenarios. By choosing several impact categories, the analyses adopted the broader perspective used in LCA rather than a one-sided focus on *e.g.* global warming. No further steps were taken to aggregate the impacts using a weight index, which would have been possible. However, these weight indices for the aggregation of impacts are based on subjective values and should only be used in special cases, since they can make the results rather one-dimensional (Rydh, Lindahl & Tingström, 2002).

The use of smaller vehicles for parts of the routes, as suggested in scenario 4 in Paper IV, could result in longer driving times and increased handling costs, but would reduce the use of heavy trucks. Apart from having lower environmental impact, the use of smaller vehicles can have positive effects on the traffic situation in dense urban areas, reducing the numbers of large vehicles and improving traffic safety, especially near schools and other locations with children, which is important.

Good planning of routes is important to make distribution more efficient and also for lowering the environmental impact. The situation at the delivery point, including the delivery time windows, is important to consider when planning. The unnecessary motor idling that occurred on some routes (in Paper III) had several negative effects, such as unnecessary environmental pollution and wasted fuel, resulting in unnecessary costs and, if it was due to queuing, a sign of inefficient planning.

In the case studies in Papers II-IV, the goal was to compare the impacts from scenarios within the studies, rather than between studies or with other studies such as those reported by Wallgren (2006) and Van Hauwermeiren *et al*., (2007). In Paper V, the energy and emissions were quantified based on weights. The results must be regarded as approximate values, since they represent a snapshot of the system during a very short period, not covering variations over time in the systems. This has to be taken into consideration when using the values. All calculations of vehicle emissions in this thesis are mainly estimates, since no actual measurements of emissions were made in the studies.

Estimates of emissions from transport could lead to greater standardisation. In Europe, standardised methodology for the calculation and declaration of energy consumption and GHG emissions in transport services should be ready this year.[17] The development of the European ARTEMIS emission model facilitates a more common way of estimating other emissions and adaptation to Swedish conditions (Sjödin *et al.*, 2009; Trafikverket, 2009, 2010), and is of great use to national researchers.

It could be easier to estimate the environmental impact of short food distribution chains rather than longer (and global) chains. This is an advantage for local food if producers want to show consumers the impact of their transport more transparently. However, the tools available for emission estimation can be better adapted for use by small-scale companies. Regardless of the distance to production areas, concern for food production and ecosystems has to remain on both a local and a global scale (Deutsch, 2004).

5.5 Quantifying emissions and energy use in distribution systems for local food

Quantification of emissions and energy use in distribution systems for food with respect to amount of food delivered is one way to enable comparison of distribution systems. The units chosen in Paper V, kWh/kg and g/kg food delivered, were intended to appear familiar to a general audience. Since kilowatt-hours (kWh) is the everyday unit used for Swedish household electric energy consumption, it was preferred over other possible energy units such as joules (J) or British thermal units (BTU). For the emissions, it was difficult to use a single unit that suited all emissions. The estimated values for *e.g.* sulphur oxides were very small when using g/kg.

Estimation of energy use and emissions from different kinds, and scales, of distribution systems for local food makes it possible to determine reference values for the environmental impacts. This is useful knowledge when evaluating changes in existing systems or selecting new systems. In such

[17] CEN/TC 320 - WI 00320025, "Methodology for calculation, declaration and reporting on energy consumption and GHG emissions in transport services (goods and passengers transport)". http://www.cen.eu/cen/Services/EHD/Sectors/Pages/Servicessector.aspx [2012-09-07]

reference data, recorded values of the economic and social impact should be included.

5.6 Developing logistics solutions for local food

Efficient logistics is a tool for improved quality and service, with minimised use of resources. By developing their logistics, local food producers can decrease their logistics costs and environmental impact. The case studies analysed in this thesis demonstrated several possible improvements (*e.g.* coordination between companies, single and multiple route optimisation, integration into existing distribution systems and changes in delivery time windows).

Collecting and analysing geographical data is becoming technically easier with the increasing availability of global positioning system (GPS) equipment and electronic maps. For a very small producer, with few occasions for transport or delivery points, it might be enough to use simpler routing solutions such as free internet map services, mobile phone solutions or a hand-held or car-mounted GPS with built-in maps. The companies handling larger material flows have in many cases invested in advanced route planning and scheduling software, such as DPS's Route Logix[18] to manage their logistics. For companies between these two categories, the use of route optimisation can greatly improve logistical performance. The choice of tools and level of utilisation is then a matter of finding the right balance between investment required and profits gained. Contracting route planning services from consulting firms could offer an intermediate solution, when time and knowledge within the own company is limited.

A balance also has to be found concerning how resources are utilised in general; *i.e.* if less or more time and money should be spent on production, refinement of products, logistics planning, or learning and implementation of new systems. For example, while a new electronic trading system may have advantages when comparing the direct costs, the time spent on learning the new system may change the balance.

In order to improve and develop the logistics system of locally produced food, it is important to make the best of the available resources and take advantage of cooperation possibilities. Producers can cooperate and coordinate transport. They can also integrate their supply chain with logistics management and physical distribution systems of larger companies. A logistics analysis needs to be the starting point for a producer when choosing between

[18] Software from DPS (Distribution Planning Software) International, http://www.dps-int.com/products/desktop/routing-software.php?ref=topNav, 2012-06-07

distribution channels to find the most profitable distribution solution. It is important for local producers to be flexible and open to different kinds of cooperation, since the prerequisites for cooperation may vary over time and from company to company.

6 Conclusions

The main conclusions from this thesis were that:

- Cooperation, optimisation and integration were approaches useful for improve logistics for local food and small-scale producers in terms of driving time and distance, and environmental impact as a whole.
- The local food marketing channels in Sweden were mainly farm shops, single retail outlets, restaurants and open markets, with operations concentrated to their own municipality and their own county. The food was mainly distributed by the producers in their own vehicles or collected by customers.
- Transport and marketing were perceived as the largest impediments to business development for local food producers and the transport-related problems were mainly caused by small volumes and distance/time-consuming transport. Authorities/regulations and lack of finances are perceived as the main impediments in general.
- Small-scale producers with a variety of products could cooperate and use e-trade systems to integrate their supply chains with large-scale retailer's logistics management and physical distribution systems to reduce logistics cost and could reduce emissions by 37-92%, compared to the reference scenario without any transport coordination between the producers.
- For distribution in urban areas, optimisation of individual routes could yield reductions of up to 34% in terms of distance and 40% in terms of time. The total number of routes could be reduced by 58%, the total route distance by 35% and emissions by about 48%.
- An integrated logistics network and optimisation of the local food distribution system in municipalities could reduce distance travelled by 64-74%, time required by 54-63% and emissions by 68-75%, compared to the

reference scenario without any transport coordination between the producers.

- Ø Freely available online tools for calculations of emissions and energy use from transport, were identified and evaluated as appropriate for use by small-scale food producers.
- Ø For local food distribution, the energy use in three of the actual Swedish distribution systems analysed in this study was estimated to be 0.34, 0.25 and 0.040 kWh per kg food delivered, respectively. Emissions were estimated for CO_2, CO, HC, NO_X, PM and SO_2, as g/kg food delivered.

6.1 Recommendations and further research

In order to address the challenges for local and small-scale food producers, and develop the local food distribution systems, several areas can be identified where improvements are required:

- Coordination of distribution for companies distributing in the same region;
  - § With similar food products, no further vehicle development is required, but support and facilitation is needed on an organisational level
  - § With different kinds of food products, development of vehicles with different temperature-insulated containers or other climate control solutions may also be required.
- Information and communication systems that are user-friendly and well adapted to the small-scale food producers;
  - § To enable effective communication and integration with other producers, and with large-scale supply chains
  - § To enable effective sustainability management and communication of relevant key indicators to target groups.
- Guidance for small-scale food producers to evaluate and develop effective distribution systems;
  - § In terms of mapping, route planning and optimisation,
  - § Identifying partners and resources, such as existing distribution systems, with collaboration potential.

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