Effects of E-Commerce on Greenhouse Gas Emissions

A Case Study of Grocery Home Delivery in Finland

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Keywords

distribution
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Summary

In this article, we present a literature review of the general and environmental effects of e-commerce in various parts of the demand-supply chain. These are further translated into effects on greenhouse gas (GHG) emissions in the food production and consumption system. The literature study revealed many opportunities for e-commerce to reduce GHG emissions in the food production and consumption system. Some possibly negative effects were also identified. Electronic grocery shopping (e-grocery) home delivery service was chosen as the subject of a case study because of its direct and indirect potential for reducing the GHG emissions in the food production and consumption system.

GHG emission reduction potential through the implementation of various e-grocery home delivery strategies was quantified. Depending on the home delivery model used, it is possible to reduce the GHG emissions generated by grocery shopping by 18% to 87% compared with the situation in which household members go to the store themselves. We estimate that the maximum theoretical potential of e-grocery home delivery service for reducing the GHG emissions of Finland is roughly 0.3% to 1.3%; however, the current and estimated future market potential is much smaller, because the estimated market share of e-grocery services is only 10% by 2005. Narrowing the gap between the theoretical and the actual potential requires a model that would simultaneously provide additional value to the consumer and be profitable to companies. To be able to achieve significant reductions in GHG emissions, system-level innovations and changes are required. Further research is needed before conclusions can be reached as to whether e-commerce and e-grocery are useful tools in that respect.

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Introduction

Climate change probably constitutes the greatest contemporary environmental challenge. To be able to achieve significant reductions in greenhouse gas (GHG) emissions, system-level innovations and changes are required. Innovative new products and services are needed, necessitating changes in the related infrastructure and organizations. This implies a need for a systems approach and a new kind of cooperation among the various stakeholders. E-commerce might offer relevant tools for coping with the climate challenge.

The food production and consumption system is important in GHG emission reduction from many perspectives, such as land use, transportation, and energy consumption. Many possibilities exist for business-to-business and business-to-consumer e-commerce in various parts of the supply chain. The future development of demand, that is, consumer behavior and preferences, and the future development of supply will have a significant impact on the potential and the effects of e-commerce.

The body of knowledge on the environmental effects of e-commerce is expanding rapidly. General studies on the environmental or sustainability effects of e-commerce include those by Wilsdon (2001) and Hurst (2001). Romm and colleagues (1999) studied the Internet economy as a potential solution to global warming. James and Hopkinson (2001) identified in their study how e-commerce may impact the food supply chain. Cairns (1999, 1998) studied the environmental effects of home delivery service and calculated that a 70% to 80% reduction in the distance driven is possible using a home delivery service for food.

The demand for this kind of research is extensive owing to anticipated growth in on-line grocery shopping. Currently, Tesco.com, the world's largest on-line grocer, has annual sales of £300 million (approximately US$470 million) in the United Kingdom, resulting in over 3.7 million home deliveries per year (Reinhardt 2001). Additionally, the retailers and suppliers in the grocery industry estimate that the market share of electronic grocery shopping (e-grocery) in Europe will be between 5% and 10% in 2005 (Powell 2000). In the United States, the estimates for the on-line grocery market growth are more or less at the same level as in Europe; Forrester Research estimates that the market share of e-grocery in the United States will be 3.2% in the year 2004 (Deering 2000).

The approach of the present study was (1) to take a broad look at the subject by reviewing literature on the general and the environmental effects of e-commerce in various parts of the demand-supply chain and (2) to translate the environmental effects into effects on GHG emissions in the food production and consumption system. A case study of the implementation of various e-grocery home delivery models was conducted because of the direct and indirect potential of e-grocery home delivery service and e-grocery for reducing GHG emissions in the food production and consumption system.

What Effects Does E-Commerce Have on GHG Emissions in the Food Production and Consumption System?

The findings from the literature study of the potential environmental effects of e-commerce and their implications for GHG emissions in the food production and consumption system are summarized in table 1 and are described in more detail in the following sections.

Sourcing

Three basic options exist for utilizing e-commerce in sourcing: create electronic marketplaces, seek new suppliers using information technology, or use information technology to enhance current supplier relationships.

Changes in the supply relations between companies have two different effects on the environment: They may affect the distance that the supplies (raw material or components) are transported, and they may play a role in reengineering the sourcing process, which can cut down overproduction (Buzzell and Ortmeyer 1995).

Electronic markets may lead to more sales between suppliers and customers that are not in

Table 1 Environmental effects of e-commerce and their implications for GHG emissions in the food production and consumption system

Part of supply chain	*Potential environmental effects of e-commerce*	*Effects on GHG emissions in food production and consumption system*
Sourcing and production	+ Reduction of overproduction	Avoided emissions from food waste and unnecessary energy consumption
	+ Reduction of inventory levels	Fewer warehouses needed, resulting in lower energy consumption
	± Distribution distances of supplies	Increased or decreased emissions from transportation (distances and mode)
Distribution	– Increased use of airfreight	Higher emissions from the need for fast transportation
	+ Increased utilization of capacity	Lower emissions from reduced traffic
	+ Avoided duplication of resources	Lower energy consumption due to fewer warehouses
	+ Avoided unnecessary transport	
Retail	+ Less waste of products	Avoided emissions from food waste and unnecessary energy consumption
	± Home delivery	Lower emissions as traffic is reduced, but the consumers may use cars for other purposes
	+ Warehouses and websites instead of stores	Warehouses consume less energy than do stores
Consumption	+ Possibility for decisions based on environmental information	Possibility for influencing the emissions from the whole supply chain, provided that interest in contributing to reduction of GHG emissions does exist
	+ Possibility for interaction with the supplier to make the whole chain more efficient	
Enabling technologies	– Internet's own use of energy	Higher emissions from increased energy consumption
	– Energy consumption of refrigerated reception boxes	

Note: In the middle column, "+ " indicates a change favorable to the environment whereas "–" indicates changes that are unfavorable.

proximity to each other. On the other hand, e-commerce may also link local producers and customers. E-commerce may thus lead to increased or decreased GHG emissions from transportation, depending on the distances and modes of transportation.

Companies can use information technology for rapid and efficient sharing of information. By doing so, they can "replace inventory with information," that is, use information to speed up processes so that smaller buffer inventories are needed (Magretta 1998). Inventory is always facing the risk of becoming obsolete, which leads to the scrapping or dumping of unused or unsold products.

Production

E-commerce places heavier pressures on costs and lead times. This results in a situation in which pull-controlled manufacturing is the most viable option for production companies (Prouty 2000). A shift to more pull-controlled production means that production follows the fluctuation of demand more accurately. If production matches demand more accurately, overproduction can be decreased.

E-commerce is usually considered a global activity. Levy (1997) pointed out that lean production is not always feasible in an international supply chain. His main points are that just-in-time deliveries with low buffer inventories and the long and unpredictable lead times for international deliveries are not a feasible combination. In e-commerce, it is not inevitably necessary to produce the goods globally in order to offer them globally. Often, it is feasible to have the production facilities near the suppliers and the customers and to manage the product and the image globally. This can be done by having production facilities in different locations or by outsourcing much of the production (Magretta 1998).

In the food production and consumption system, the potential for increasing or decreasing GHG emissions from transportation, for decreasing the energy consumption of storing the products, and for avoiding overproduction and waste depends to a great extent on the development of demand and production at the national and international levels.

Distribution

Shortening of Delivery Lead Times

Time is becoming a scarce resource for the companies of today (Stalk and Hout 1990). E-commerce customers frequently demand faster deliveries with little or no delivery charge (Jedd 2000). The result is that all sellers engaging in e-commerce have to move to shorter delivery lead times in response to the shorter delivery lead times of their competitors.

The shortening of applicable delivery lead times piles up pressures on many, especially global companies. Many companies, especially in industries with highly volatile demand and with short product lead times (Fisher 1997), may solve the problem by switching from sea and land transportation to airfreight (Harari 1999). The switch to airfreight would increase the environmental effects of e-commerce considerably, because airfreight is environmentally much more damaging than sea, rail, or road transportation (VTT 2000a, 2000b, 2000c, 2000d). The change to airfreight, however, depends on the value of goods in relation to their weight and volume.

Utilizing Resources and Capacities More Efficiently

Outsourcing of business processes is important for allowing companies to focus on their core competencies (Prahalad and Hamel 1990); however, outsourcing of supply-chain operations is also important, because, if easy, it makes the distribution process more adaptable and scalable (Kiely 1997). This means that short-term partnerships can be used more efficiently.

E-commerce can help companies outsource logistics operations. Cameron and Gormely (1998) expected supply chains to develop from interorganizational integration via supply-chain collaboration to communities of compatible supply-chain partners. They believed that sometime in the near future, innovative companies will go beyond integration and form or join small supply-chain communities. The size of these communities could be up to 20 companies, and one company would play the dominant role. Narus and Anderson (1996) stated that forward-looking companies will have to develop adaptive supply chains. They believed that companies can develop adaptive supply chains by sharing capabilities with other, possibly competing, organizations.

What could easier logistics outsourcing and the forming of supply-chain communities mean for the environment? Even if the demand for a single product of one firm is highly volatile, the aggregated demand of the whole product group is usually quite stable (Blomqvist 2000). By better and more fluent cooperation, companies could establish better transportation fill rates. This would make distribution more efficient and reduce the GHG emissions of transportation (VTT 2000d).

Using Radio-Frequency Identification to Solve Problems Related to Increased Complexity of Logistics

E-commerce, whether business-to-business or business-to-consumer, often increases the number of delivery addresses, which leads to smaller shipments (Rickhardson 2000) and more difficult logistics (Brooksher 1999; Seideman 2000). Products must be sorted rapidly and accurately in order to have rapid deliveries of differentiated material flows.

At present, it is much more costly to handle and sort shipments than to carry them as freight (Heikkonen and Välttilä 2000). This has led to the situation that large quantities of packages are carried over long geographic distances to be sorted somewhere else and are then possibly carried back to near the starting point. Transporting products to centralized distribution centers or hubs is not environmentally favorable.

One solution to the problem of rapid and accurate sorting that e-commerce could facilitate would be the increased use of radio-frequency identification (RFID) tags. British Airways (Nelms 1999) and Lynx Express (Retailers scurry to the Internet 1999) have successfully used this wireless identification technology to achieve significantly faster and more accurate sorting and distribution.

Products can be identified effortlessly with RFID[1] tags because (1) unlike bar codes, they do not require a line of sight in order to be read; (2) they can be read through nonmetallic materials; and (3) about 60 tags can be read simultaneously (Jones 1999; Boxall 2000; Lindström 2000). The tags are also resistant to temperature and other environmental factors and can be read and rewritten at least 300,000 times (DeJong 1998).

If all shipments were marked with RFID tags, the sorting could be done with minimum manual intervention. This would reduce the costs of sorting and therefore favorably change the balance of the trade-off between sorting and transportation. An RFID tag can also be used as a distributed database of transportation information (Gurin 1999), thus making the shared use of distribution centers more easily applicable.

Retailing

In business-to-consumer e-commerce, for instance, a warehouse can contain far more products per square meter than a retail store. Warehouses themselves also typically use far less energy per square meter than retail stores. Thus, products sold over the Internet would likely consume less energy per product than traditional retail-based sales (Romm et al. 1999).

If e-commerce facilitates the use of wireless product identification technologies, it can help make a grocery chain more accurate while simultaneously reducing the spoilage problem. Sainsbury's is an example of a company that has, with the collaboration of some of its suppliers, used wireless product identification to reduce spoilage. The result has been radically improved control of the perishables supply chain, an ability to reduce the spoilage problem, and increased handling efficiency (Burnell 2000; Boxall 2000). Although the perishable groceries that have passed their use-by or best-before dates must still be dumped, reduction of the spoilage reduces environmental impacts and conserves natural resources. Sainsbury's could not implement the system at full scale, however, because the necessary parts for the system were not available in the marketplace (Banks 2001). The lack of service providers able to deliver complete systems is restraining the emergence of RFID-based logistics solutions. Thus, the effects of RFID on GHG emissions from distribution or retail are not realizable in the near future.

An e-commerce retailer usually offers to deliver the goods to the consumer's home. The service provider can handle the transportation of goods to the consumer's home much more efficiently than the consumer could. This means reduced distance driven and lower GHG emissions, provided that consumers do not use their cars more for other purposes.

Consumption

E-commerce also enables the retailer to offer more services to the consumer. A company may offer grocery replenishment services to consumers (Smaros and Holmström 2000) or even coordinate deliveries with planned household activities (Smaros et al. 2000). The resulting interaction with the consumer can also help make the supplier's own processes more efficient, thus increasing environmental efficiency. E-commerce also provides the possibility of disseminating environmental and social information on products and services to consumers and marketing "best buys" (Joseph and Garnett 2001). Changes in the demand for products and services can influence the emissions from the whole supply chain, provided that consumers are interested in contributing to the reduction of GHG emissions through environmentally sensitive product choices.

Case Study of E-Grocery Home Delivery Service

E-grocery home delivery service was chosen as the subject for this case study because of the direct and indirect potential of e-grocery for reducing GHG emissions.

Various e-grocery home delivery service models may have a strong impact on the development of the traffic environment in population centers and thus on GHG emissions. Home delivery operations are developing rapidly at present, and current knowledge of last-mile operations is imperfect as compared with the other elements of supply-chain operations.

E-grocery home delivery service is considered a crucial element as far as the realization of home delivery services in general is considered. If e-grocery home delivery service becomes successful, it will be relatively easy to integrate home delivery of other products into it. E-grocery also provides an opportunity for disseminating environmental and social information on products and services to consumers. Possible changes in consumer behavior, and thus demand for products and services, could influence the whole supply chain and thus have a more significant impact on GHG emissions than e-commerce has on the supply side.

The test area selected in this study covered part of the Helsinki metropolitan area in Finland. This selection was made because of easy access to the data needed and the strong development going on in this area.

Background

Background information regarding the overall traffic environment in Finland and in the test area, metropolitan Helsinki, is required for an understanding of the simulation results and conclusions of this case study. The amount of overall road traffic both in Finland and in the Helsinki test area can roughly be divided into two main categories: 15% for the transportation of goods and 85% for passenger and professional business traffic (Mäkelä 1999; Nummenpää and Ollikainen 1999; YTV 2001). The yearly distance driven is presented in figure 1.

Traffic in the Helsinki metropolitan area is increasing constantly. According to forecasts made by the Finnish Road Administration, the estimated increase in the amount of overall traffic in Finland is 38% (for car traffic, 36%) during the period between 1997 and 2030. During the same period, the estimated increase in the amount of traffic overall in the Helsinki metropolitan area is expected to be 50% (FINRA 2001; Tielaitos 1999b).

Estimations of future traffic amounts can also be analyzed by studying the past development of passenger traffic. The distance driven per day in Finland increased by 42% during the period 1974–1992, with 22% of that increase occurring during the period 1986–1992. The time used for traveling and the number of trips per day, however, have remained at approximately the same level as in 1974. This indicates that the usage of cars enabling higher speeds increased and that it became possible to travel longer distances in roughly half the time required previously (Pietilä 1993; Tielaitos 1999a). Despite these trends, we believe that introducing a food home delivery service could be a means to slow the increase in the amount of overall road traffic or even reduce it.

To understand the potential reduction of GHG emissions through food home delivery services, we need to study more closely the overall traffic proportions. The share of passenger traffic can be divided into subcategories including transport modes such as car, bus, train, aircraft, pedestrian, and bicycle. On the basis of an earlier study (Pastinen 1999), we estimate that, if personal business and other purchasing trips are excluded, the share of the distance driven on trips for the purchase of daily goods is around 12% of the overall road traffic. This 12% can be regarded

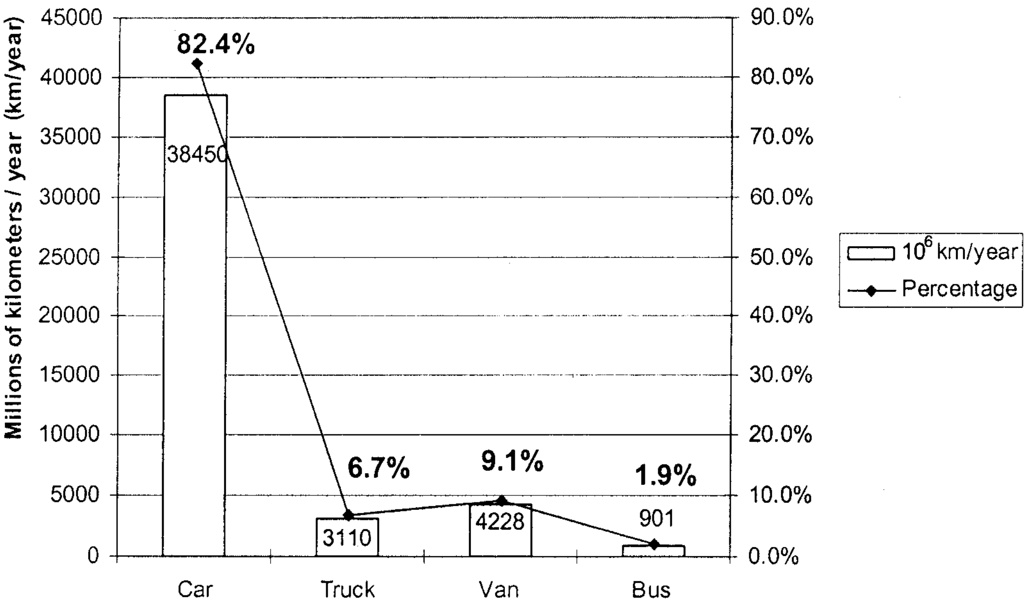

Figure 1 Proportions of different road traffic types in Finland, 2000. *Source:* Data from VTT (2001).

as the potential for traffic reduction through a home delivery service. This estimate is also supported by earlier estimates made by Cairns (1999).

Some potential incentives for customers to change their shopping habits and to use on-line grocery and food home delivery services are possible cost reductions, improved service level, savings of time, improvement in the quality of air in the neighborhood, and reduction of traffic in the neighborhood.

Home Delivery Simulation Settings

The simulation results to be presented in this article were obtained using RoutePro (CAPS Logistics 2001), a routing software tool from CAPS Logistics. RoutePro algorithms utilize digital maps of the selected test area, enabling exact simulation outcomes, such as the distance driven. In the simulation model, each scenario is constructed in two steps: First, orders are generated, and, second, they are routed using the routing software.

In the analysis, the routing is limited by the volume of orders, the vehicle characteristics, and by the two time windows included in each order file. The delivery time window, specified by "drop-off start" and "drop-off end," depends on the type of delivery reception. If an unattended reception model is used, the delivery time window equals the delivery hours. With models requiring attended reception, the delivery hours for each order are divided into time windows defined by the service model and the actual time of purchase from traditional grocery shopping point-of-sale data. The pickup time window, which describes when the orders have to be loaded into a vehicle at the distribution center, is determined in the order file by using "pickup start" and "pickup end." We assume that the delivery is available for pickup at the last possible ordering time for the respective delivery time window. Figure 2 presents an example of the relationship between the time windows in the order file. The service model specifies the latest possible arrival time for each order. The latest possible arrival time is then used as the starting point of the pickup time window. In the simulation model, the pickup time ends as the delivery time ends.

The routing is limited not only by the time windows, but also by the vehicle characteristics and the volume of orders. The limiting values of the vehicle fleet in the simulations are as follows.

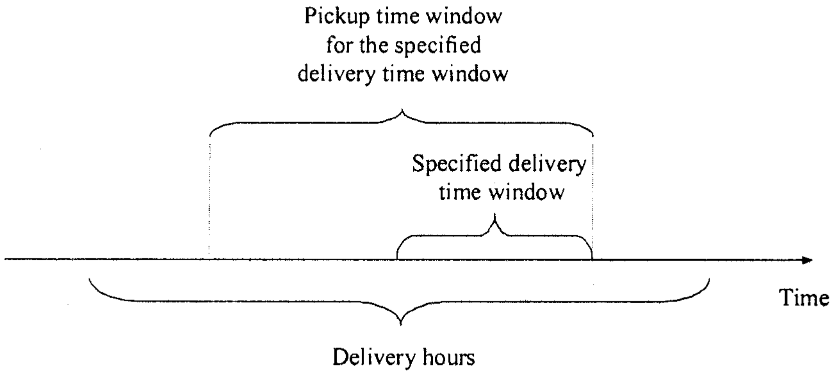

Figure 2 Order file time windows.

- Maximum of 60 orders per route
- Maximum of 3,000 L per route (the real volume of the van is normally 10 to 12 m^3)
- Working time maximum: 11 hr per van
- Working time maximum: 5 hr per route
- Loading time per route: 20 min
- Drop-off time per customer: 2 min

Data Used in the Simulations

The data used in the simulations constitute a sample of traditional grocery-shopping point-of-sale data from one of the largest grocery-retailing companies in Finland. Exact receipt information was collected from five grocery stores of this chain during a representative week in October 1999. These data include, for example, quantities, volumes (liters), dates, shopping times, and prices of grocery loads bought by regular customers. The data were kept anonymous to protect customer identity.

The data selected for the simulations were limited in a number of ways. The order size taken into account was limited to orders priced over €25. This selection was made to provide a reasonable size for the e-grocery shopping basket for the home delivery simulations. The second limitation was the customer's residence, which had to be within the boundaries of the test area. The test area (135 km^2) selected for the simulations covered part of the Helsinki metropolitan area in Finland. The number of inhabitants in the test area is approximately 202,000, and the number of households is about 89,000 (Statistics Finland 1998).

Finally, in the simulations, the demand, modified from traditional grocery shopping data, contained the exact point-of-sale data from 1,639 orders. The orders were made during six shopping days of one week by 1,450 anonymous regular customers located in the selected test area. The number of orders varied between 160 and 462 per day. In the simulations, the orders were delivered from a single distribution center to the customers' household addresses. The distribution center was located in a suburban area next to an existing store. For the simulations, four home delivery models (cases 1 through 4) were identified. Cases 1 and 2 require attended reception, whereas in cases 3 and 4, unattended reception is enabled by using a customer-specific reception box (figure 3). Case 5 describes the present situation, where consumers use their own cars for driving to and from the actual store where they do their shopping. The cases used in the simulations are described in table 2.

In cases 3 and 4, customer-specific reception boxes are used. A reception box is equipped with a refrigerator-freezer unit, enabling compartments for frozen and chilled food. In the reception box, there is also a room-temperature compartment. A customer-specific reception box can be installed, for example, in the customer's garage or the yard of their home.

Potential Effects on the Distance Driven and GHG Emissions

In this article, we concentrate on analyzing the possible environmental effects of the home

Figure 3 A customer-specific reception box.

Table 2 Description of the cases in the simulations

Case	*Description*
1	E-grocery home delivery in three two-hour time slots between 17:00 and 21:00
2	E-grocery home delivery in one-hour time slots between 12:00 and 21:00
3	E-grocery home delivery to reception boxes (see figure 3) between 8:00 and 18:00
4	E-grocery home delivery once a week per customer between 08:00 and 18:00 to reception boxes (simulating the best possible case from the E-grocer's point of view, where orders are sorted by postal codes and divided evenly on all delivery days)
5	All 1,639 "orders" delivered separately, simulating the situation where households do the shopping themselves using their own cars

delivery models; the cost effects of these solutions have already been presented and analyzed in Punakivi and Saranen (2001). According to our simulations, all the home delivery service models are more environmentally friendly than the current situation, where customers visit the store using their own cars. Figure 4 presents the average distance driven per order using the home delivery models compared to the current situation where household customers visit the store, driving back and forth with their own cars.

According to our simulation results, as well as other studies (Granfelt et al. 1995) validating our results, in Finland the one-way distance to the grocery store averages 3.5 km. Thus, in the current situation, the average distance driven per shopping trip is 6.9 km. A case-by-case study of the average distance driven per order with the selected e-grocery home delivery models (figure 4) follows.

When the e-grocery home delivery service provider offers customers a 1 hr delivery time window (case 2), the delivery vehicle needs to drive back and forth in the delivery area to meet the promised delivery-time windows. Additionally, the delivery-time windows limit the vehicle capacity utilization dramatically, as can be seen in figure 3. The average distance driven per order in case 2, however, is only 46% of the distance driven in the current situation (case 5), where customers use their own cars. To gain efficiency, even limiting the service time windows to three 2 hr delivery slots (case 1) enables better route and schedule optimization, leading to a significant reduction in the distance driven and resulting in only 24% of the distance driven compared with the current situation. This operating model is efficient, but an even better situation is attainable through the use of reception boxes (cases 3 and 4), which enable unattended reception. E-

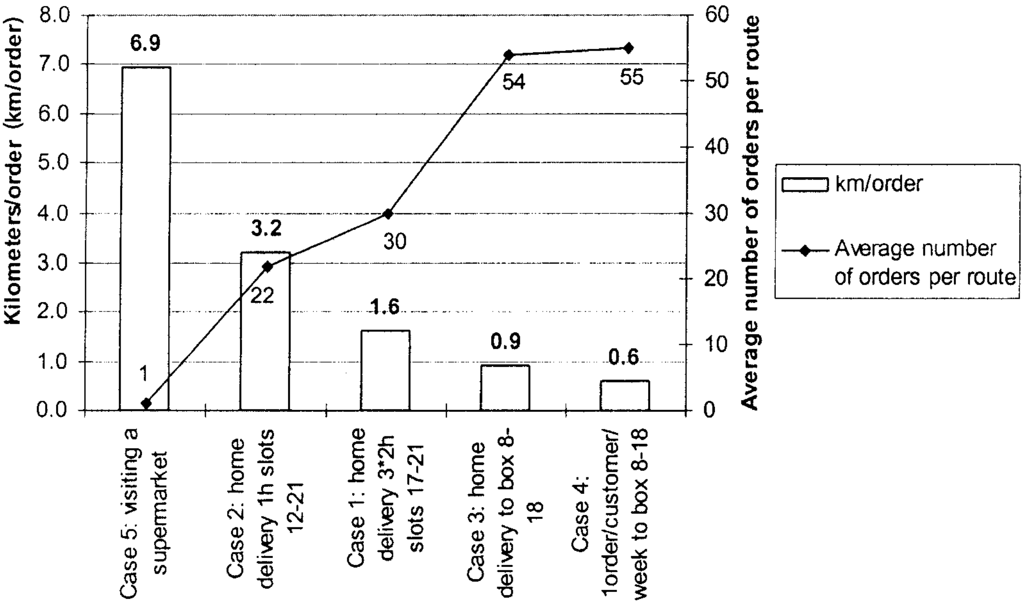

Figure 4 Average distance driven per order and average number of orders per route.

grocery reception boxes at customer households and an open (0800 to 1800) delivery-time window enable the best possible optimization of the schedule/routing and vehicle capacity utilization. In case 3, the distance driven is only 13% of the distance driven in the current situation. Furthermore, case 4 simulates the best attainable situation in home delivery transportation. In case 4, the orders are sorted by postal code and divided evenly among all six delivery days of the week, whereas in case 3 the orders are delivered on the original shopping date. According to the simulation results in case 4, the distance driven decreases dramatically, being only 7% of the distance driven in the current situation. In reality, the service provider could attain case 4 through its pricing policy or service-area definition.

In addition to the distance driven, the type of the vehicle, its fuel efficiency, and the fuel used have a strong impact on GHG emissions. The effect has been calculated from the simulated distance driven by using the emission factors for CO_2, CH_4, and N_2O defined in LIISA 2000 software (VTT 2001). In the calculations, the coefficients for cars equipped with catalytic converters are used. As to the home delivery vans, the coefficients for vans equipped with diesel engines are used. The emission factors used in the calculations are shown in table 3. International Panel on Climate Change (IPCC) factors 21 for CH_4 and 310 for N_2O were used for calculating the CO_2 equivalent emissions.

The results in figure 4 and table 4 show that home delivery service creates a significant potential for traffic reduction as compared with the current situation, where customers visit the store using their own cars. In the best possible case, this reduction in the distance driven could be as much as 93% (case 4). In most cases, however, the reduction would be somewhere between 54% and 93%, depending on the home delivery model used. These results are in line with research by Cairns (1998), in which a mileage reduction potential of 77% was found. In reality, however, the results are highly dependent on the local road networks, rush hours, and vehicles used, which complicates the generalization of the results. Our results also reveal wide variations in the potential for reducing the distance driven and GHG emissions among the different service models, which have not been reported in other studies.

Analyzing the Potential for Reducing GHG Emissions

The IPCC has introduced a concept of different GHG emission mitigation potentials (IPCC 2001):

Table 3 Emission factors given in grams of gas emitted per kilometer driven (g/km)

	g CO_2 */km*	*g* CH_4*/km*	*g* N_2O*/km*
Car, gasoline	159	0.014	0.03
Van, diesel	297	0.0015	0.008

Note: The car emission factors given here are for gasoline engines equipped with catalytic converters.

- Market potential, meaning the actual use of environmentally sound technologies and practices
- Economic potential, which is approached through creation of markets, reduction of market failures, and increased financial and technological transfers
- Socioeconomic potential, which is approached through adoption of changes in behavior, lifestyle, social structure, and institutions
- Technological potential, which can be achieved by implementing technology that has already been demonstrated
- Physical potential, meaning a theoretical upper limit

Barriers at different levels cause the actually realized market potential to be significantly smaller than the technological or physical potential. Opportunities exist for overcoming these barriers by introducing various policies, measures, and instruments.

In the next two sections, we discuss the theoretical maximum potential and the actual market potential of e-grocery home delivery service for reducing GHG emissions in Finland, the former being especially relevant from a policy perspective and the latter from the perspectives of the service provider and the consumer.

Theoretical Maximum Potential of E-Grocery Home Delivery Service for Reducing GHG Emissions in Finland

Depending on the home delivery model used, it is possible to reduce the GHG emissions by 18% to 87% from the situation in which households do the shopping trips using their own cars. The results indicate that e-grocery home delivery service may have a significant potential to reduce GHG emissions depending on the selected operations model.

A theoretical maximum potential of e-grocery home delivery service for reducing GHG emissions in Finland can be estimated on the basis of the results of our case study. The transport sector accounts for about 15% of Finland's GHG emissions (Aarnio et al. 1998). The GHG emissions from road traffic were 11 million tons (Mt)[2] in 1998, of which cars accounted for 6.3 Mt (KTM 2001). We estimate that the current GHG emissions from grocery shopping travel are 1.1 Mt CO_2, which accounts for 1.4% of Finland's GHG emissions. E-grocery home delivery service can lead to a GHG emission reduction of 0.19 to 0.95 Mt CO_2, which would reduce emissions in Finland by roughly 0.3% to 1.3%.

The potential of e-grocery home delivery service to reduce the GHG emissions in Finland is relatively small. The potential of reducing the GHG emissions of a country, however, depends on the share of GHG emissions from the traffic sector and grocery shopping. In countries where the share of GHG emissions from the transportation sector is higher, for reasons such as the structure of the economy and climatic conditions, the GHG emission reduction potential of e-grocery home delivery service can also be higher. The GHG emission reduction potential also depends on the size of the metropolitan area served, population density, zoning practices, and the number of suitable market areas for e-grocery services.

Nevertheless, simulation-based calculations of this type, which take into account the distance driven and traffic emissions, provide a simplistic view of the issue. Here we assumed that, in the current situation, all of the 1,450 ordering customers, that is, 1.6% of the households in the test area, used their own cars to do 1,639 shopping trips. To estimate the overall potential for traffic reduction, we should take into account the fact that, on average, only 70% of household customers in Finland have cars. About 55% of all shopping trips are made by car. On average, 31% of the customers walk and about 5% use public transportation, whereas 8% use bicycles or mopeds. Additionally, on average only 75% of customers come to the store directly from home, and only 76% of car owners use their cars when visiting the store (Granfelt et al. 1995).

Table 4 Summary of results

Case	Distance driven (km) per 1,639 orders	Reduction in distance driven compared with case 5	Vehicle type	GHG emissions, tons of CO_2 equivalent	GHG reduction compared with case 5
1	2,676	76.5%	Van, diesel	0.80	58.2%
2	5,267	53.7%	Van, diesel	1.58	17.7%
3	1,525	86.6%	Van, diesel	0.46	76.2%
4	822	92.8%	Van, diesel	0.25	87.2%
5	11,365	0	Car, gasoline, cat.	1.92	0

A more realistic view of the issue could be obtained by taking into account the share of households having cars and the habits of customers using cars when visiting the store. It would also be important to include information on whether the customers come to the store from home or on their way home from work/hobbies. The extra distance driven by customers shopping on their way home from work or other activities should be included in the macrolevel analysis. Another question is the shopping behavior of the non–car owners. If they are the most likely users of home delivery services, the result might be extra traffic. According to Cairns (1999), however, 61% of the food home delivery customers of the "Food Ferry" are owners of at least one car. Of car owners, 74% were using their cars less because of shopping with the Food Ferry.

Market Potential

In the calculation of the theoretical maximum potential, the market share of e-grocery was estimated to be 100%. The current estimate for the market share of e-grocery, 10% by 2005, decreases the GHG emission reduction potential accordingly. In addition to the development of the market share of e-grocery in general, the home delivery models offered by service providers and chosen by the customers have a significant impact on the resulting GHG emission reduction.

In order to increase the share of e-grocery, a home delivery model that would simultaneously provide additional value to the consumer and be profitable to companies is needed. Punakivi and Saranen (2001), using these same data, identified significant improvement in the economic potential of current home delivery models. When solutions offering unattended reception, attended reception, and one-hour time windows were compared, a cost reduction potential of up to 60% was found. The solution offering unattended reception is thus the most attractive from the perspective of the service provider. The model showing the highest potential for economic improvement also has the highest potential for reducing GHG emissions. The implementation of this model would mean significant investments and behavioral changes by the consumer, who would have a reception box and need to change his/her shopping behavior considerably, that is, plan his/her shopping so that one delivery per week would suffice.

Conclusions and Suggestions for Further Research

The literature study revealed many possibilities for e-commerce to reduce GHG emissions in the food production and consumption system. Some potentially negative effects were also identified. E-grocery home delivery service was chosen as the subject of this case study because of the direct and indirect potential of e-grocery for reducing GHG emissions in the food production and consumption system.

The results of this case study indicate that home delivery service creates significant potential for traffic reduction compared with the current situation, where customers visit the store using their own cars. The significance of the potential for reducing the distance driven and GHG emissions compared with current practice depends on the type of home delivery model offered by the service providers and chosen by the consumers. The total GHG emission reduction potential of e-grocery in Finland is relatively small because the transportation sector is responsible for only 15% of the GHG emissions. In countries where the transportation sector's share of GHG emissions is more significant, the potential for reduction based on e-grocery and e-commerce services with home delivery is higher.

Further study related to e-grocery home delivery service is required. More information is needed about the estimated theoretical potential of e-grocery home delivery service and the gap between the theoretical and likely potential.

Several issues related to the estimated theoretical potential for the reduction of GHG emissions call for further study, such as the actual driving and shopping habits of car owners and the shopping habits of those without cars. Currently, the actual potential for reducing GHG emissions through e-grocery home delivery service is much smaller than the theoretical potential. The size of the actual reduction depends on the efficiency of the home delivery model, local circumstances, and the future market share of e-commerce. Several economic and behavioral barriers, as well as driving forces, will influence the development of the market share of e-grocery and selection of home delivery model.

Narrowing the gap between the theoretical and the actual potential requires a model that simultaneously provides added value to consumers and is profitable to companies. The model showing the highest potential for reducing GHG emissions in this study was a service that provided the greatest flexibility in arranging efficient delivery, making it attractive for the service provider. The customer, in this model, should have a reception box and plan his/her shopping so that one delivery per week would suffice. The implementation of the model requires significant changes in the shopping habits of customers and cooperation of a new kind between retailers and their customers.

To be able to achieve significant reductions in GHG emissions, system-level innovations and changes are required. Further research is needed before conclusions can be reached as to whether e-commerce and e-grocery are useful tools in that respect. The GHG emissions in the whole food production and consumption system need to be studied, and the overall effect that e-commerce may have on this system's emissions must be determined. Linkages among the various parts of the demand-supply chain and the combined effects on the whole system should be taken into account. The future development of demand, that is, consumer behavior and preferences, and the future development of supply both have a significant impact on the potential of e-commerce and its effects in the food production and consumption system.

Other developments related to food production and consumption systems, such as the recent "food crises," may shift consumer preferences from low-cost to high-quality and local production. Could this increased awareness also include the GHG effects and result in changes in diet and in preference for products that cause lower emissions in the supply chain? This leads us to what is probably the most challenging question on the effects of e-grocery use: What are its secondary effects? One argument for e-grocery home delivery service is that it can save time and money. The interesting question is how the time and money saved will be spent and whether the substituting activity will merely lead to higher GHG emissions.

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Note

1. Editor's note: For a discussion of RFID tags in environmental management, see "Toward Trash That Thinks: Product Tags for Environmental Management" by Saar and Thomas, pages 133–146 in this special issue of the *Journal of Industrial Ecology*.
2. Each use of "ton" in this article refers to metric tons unless specified otherwise; 1 metric ton = 1 Mg (SI) ; 1.1 short tons.

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