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Greenhouse Gas Emissions in the Life-Cycle of Carrots and Tomatoes

methods, data and results from a study of the types and amounts of carrots and tomatoes consumed in Sweden. With arable land use.

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Greenhouse Gas Emissions in the Life-Cycle of Carrots and Tomatoes -

methods, data and results from a study of the types and amounts of carrots and tomatoes consumed in Sweden during 1992-1993. With arable land use.

Abstrakt/Abstract

The report was written as a part of an on-going research project called "Environmental Impacts of Quantifiable Consumption Patterns".

Methods, data and results from an assessment of the arable land use and some greenhouse gas emissions during part of the life-cycle of the consumed carrots and tomatoes in Sweden during 1992-1993 are presented in the report. The life-cycle was delineated to transportation, storage, farm production and production of fertilisers. Carrots from six countries and tomatoes from four countries were analysed. The study is reported with full transparency.

The results are presented as the use of arable land (in m^2) and as the amount of greenhouse gas emissions (in g CO_2 equivalents) required to sustain current Swedish consumption patterns of carrots and tomatoes. Emissions per kg of consumed tomato were 10 times higher than for carrots. Emissions from carrots were lowest when they were produced within or close to Sweden, while the opposite was the case for tomatoes.

The key issues in the life-cycle of the analysed carrots and tomatoes are identified and discussed. The general conclusions are that storage may be a key-issue for vegetables with a long durability and adapted to a northern European climate. For vegetables with short durability, the key issue may be transportation if they are not adapted to a northern European climate but still cultivated in the open. The key-issue for vegetables with a short durability may be energy requirements during farm production if the vegetables are not adapted a northern European climate and therefore cultivated under glass.

Nyckelord/Key words
food consumption, carrots, tomatoes, Life-Cycle Assessment, greenhouse gas emissions, food consumption patterns.

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1. Introduction

This report was written as a part of an on-going research project called "Environmental Impacts of Quantifiable Consumption Patterns". The aim of this project is to develop methods for assessing environmental impacts from consumption patterns, and to use these methods for calculating greenhouse gas emissions during the life-cycle of various foods. The project was divided into several parts. During the first and exploratory part, a tentative methodology for assessing environmental impacts of consumption in a life-cycle perspective was developed. [1] The second part included a trend analysis of the Swedish food consumption through the consumer period (1960–1992) with respect to trends expected to influence the environment. [2] The results from the trend analysis were used to select certain foods for a quantitative analysis of the arable land required for their consumption and the greenhouse gas emissions during the life-cycle of these foods.

Methods, data and results from an assessment of the arable land use and some greenhouse gas emissions during part of the life-cycle of the consumed carrots and tomatoes in Sweden during 1992-1993 are presented here. The life-cycle was delineated to transportation, storage, farm production and production of fertilisers. Carrots from six countries and tomatoes from four countries were analysed. The study is reported with full transparency as recommended in current methodological proposals for Life-Cycle Assessments, [3] and, whenever applicable, the recommended methods and vocabulary have been used. The results are presented as the use of arable land (in m^2) and as the amount of greenhouse gas emissions (in g CO_2 equivalents) required to sustain current Swedish consumption patterns of carrots and tomatoes. The methods and the data will help further understanding of global impacts from food consumption. For example, the relative importance of different parameters is available in tables where results are given in CO_2 equivalents. The same tables also contain information about emissions depending on the countries of consumption origin. For those interested in comparing the differences in emissions from consuming carrots versus tomatoes, Tables 49-51 are recommended.

The analysis presented here is currently expanded to include several other fresh vegetables, fresh potatoes and meat. At a later stage, future patterns of food consumption will be explored in a scenario study and emissions of greenhouse gases and the use of arable land will be estimated.

2. Goal Definition and Scoping

The objective of the Goal Definition and Scoping in an LCA is to give a clear understanding of the purpose of the study, the studied systems, and the intended applications including all its limitations. [4] In the Goal Definition and Scoping part, the functional unit (the unit to which all data are related), the system boundaries, the geographical limitations, the data requirements, the chosen impacts categories and the critical review process should be explained.

2.a Goal

The *goal* of this study is to:

* present and use methods for quantifying environmental impacts from consumption patterns
* present and discuss data for the above mentioned purpose.

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[1] Carlsson A. 1994. *Developing a Methodology to Assess Environmental Effects of Consumption Patterns- a case study*. Department of Environmental and Energy Systems Studies, Lund University, Institute of Technology, IMES/EESS Report No. 18, 51 p.

[2] Carlsson A.1995. *Swedish Food Consumption and the Environment- a trend analysis during the period of consumerism*. Department of Environmental and Energy Systems Studies, Lund University, Institute of Technology, IMES/EESS Report No. 19, 40 p.

[3] Lindfors L-G. 1995. *Nordic Guidelines on Life-Cycle Assessment.* Nordic Council of Ministers, Nord 1995:20, Copenhagen, 222 p.

[4] Lindfors L-G. 1995. Op cit. P. 25

* identify key-issues in the life-cycle of the studied products

2.b Functional Unit

The *two functional units* of the study are the annually consumed amounts of carrots and tomatoes by one person in Sweden during 1992-1993. These amounts were 6,8 kg of carrots and 7,2 kg of tomatoes.

The emissions, or use of arable land, are expressed as m^2 arable land per capita and year or g CO_2 equivalents per capita and year. When the emissions per capita and year ($g*capita^{-1}*year^{-1}$) were divided by the consumed amount per capita and year ($kg*capita^{-1}*year^{-1}$), emissions per amount of product were obtained ($g*kg^{-1}$). Emissions per kg of product were used when comparing the differences between the consumption patterns of carrots and tomatoes. Table 1 contains information about the countries of consumption origin for the consumed amounts of carrots and tomatoes. Countries of consumption origin are the countries where the carrots and tomatoes were produced.

2.c Geographical Limitation

The study has *no geographical limitation except for that only the consumed amounts relevant for Sweden were analysed.*

The carrots and tomatoes were tracked back to the countries of consumption origin according to the following criteria

* Swedish produced products were always analyzed.
* Imported products were tracked back to the countries of consumption origin if the imported share from that specific country was 5 % or more of the total imported amount. All countries from where the imported amounts were less than 5 % were grouped together in a category called "other countries". The methods for estimating greenhouse gas emissions from products from "other countries" are fully explained in each appropriate data/ inventory and characterisation section in this report. The overall principle has been to assume a worst-case scenario resulting in high emissions rates from products from "other countries".

Worst-case scenarios were chosen in order not to underestimate the possible influence of emissions of products from "other countries". While the amounts imported from such countries were small, many of these countries are situated far away from Sweden with potentially high emissions during, for example, transportation.

2.d Impact Category

The study is limited to the *impact categories* of Arable Land Use and Global Warming. Arable Land and Global Warming were chosen as the sole impact categories for several reasons. One was that emissions of greenhouse gases affects the global commons and therefore such emissions should be of concern for producer of fertilisers, farmers and consumers alike. Arable land is likely to become an increasingly scarce global resource with a growing global population and competing demands for land. Thus, both the use of the Environmental Space [5] for greenhouse gas emissions and arable land may be among the more contentious issues in the coming decades. A second reason was that emissions of substances with mainly local and regional impacts may be hard to characterise when the geographical span is as large as it is in this study.

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[5] The Environmental Space has been defined as "the quantity of energy, water, land, non-renewable materials and wood that can be used in a sustainable fashion" according to the Wuppertal Institute. 1995. *Towards Sustainable Europe The study.* Friends of the Earth Europe, Luton, United Kingdom, 215 p. P. 11. The Environmental Space is commonly expressed in kg, litre, m^2 or MJ per capita and year.

2.e System Boundary

The system boundary is explained in Figure 1. Included in the analysis are emission of greenhouse gases during crop farming, production and transportation of fertilisers as well as emissions during storage and transportation from the producer of the vegetables up to the retailer.

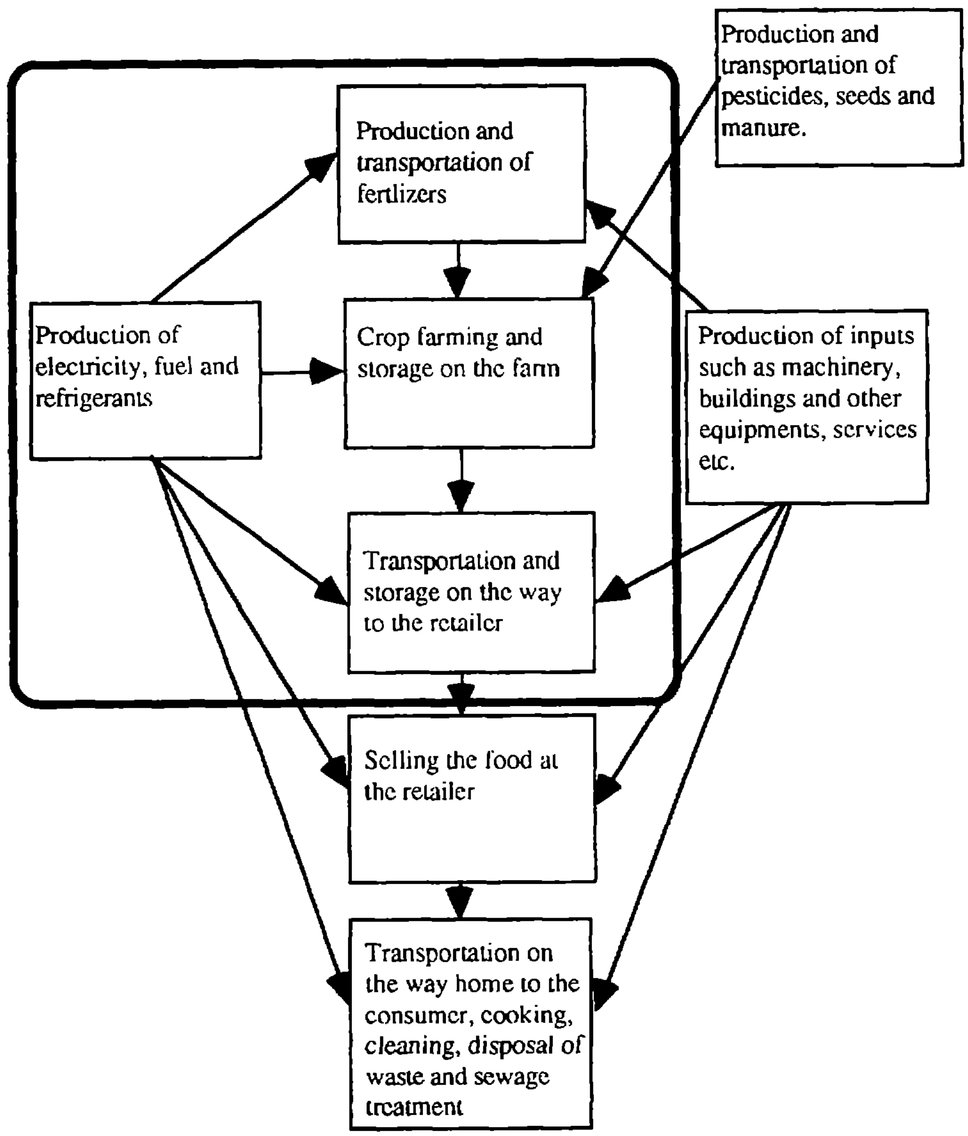

Figure 1: System boundary for the analysis of greenhouse gas emissions during the life-cycle of some consumed tomatoes and carrots (thick line).

2.f Data

Published articles in scientific journals or published official records were used as sources of data whenever possible. This material was complemented with information obtained during interviews with representatives of branch organisations and companies. Special care was taken to ensure a high data quality in the interview material. Notes were, whenever considered appropriate, promptly sent to the interviewees for correction and whenever possible, data obtained during the interviews were compared with data obtained from other interviewees.

Most data reflect the situation during the beginning of the 1990s. Average values or data and estimations for single years have been used with the objective of finding as reliable and relevant information as possible. The overall goal was to gather data reflecting the average situation in the countries of consumption origin during the time period studied. In practice, data types of class III [6] were used in most cases.

Emissions of greenhouse gases *included* in this study are:

* CO_2 (including pre-combustion emissions)
- from fuels necessary to run lorries, planes, ships, tractors and from the fuels used for generating the necessary electricity for storage and irrigation pumps. CO_2 emissions from the use of energy during the manufacturing of fertilisers are also included.

* refrigerants affecting climate change (including emissions during production)
- from leaking transport refrigeration equipment in lorries, planes and ships and from refrigeration equipment in stationary storage facilities.

* CH_4
- from hydropower dams used for producing the electricity needed for storage and emissions of CH_4 during the production of fertilisers.

*N_2O
- from the manufacturing process of fertilisers and from farm land as a result of application of N-fertilisers.

Not included in the analysis are, for example, emissions of greenhouse gases during the manufacturing and transportation of inputs for farm production such as seeds, pesticides, building materials and machinery or emissions from the manufacturing of transport equipment, tarmac and storage facilities. Neither included are emissions during storage at the retailer or at home as well as emissions during transportation to and from the consumers home and the shop. Emissions of N_2O and CH_4 during fuel combustion were not included due to lack of data. Possible consequences of some these exclusions are discussed in Carlsson A., 1997. [7] The consequences of excluding the production of pesticides and the glass needed for greenhouses are negligible. The consequences of excluding transportation to and from the consumers home and the shop are probably negligible for tomatoes but of some importance for carrots.

2.g Critical Review

A critical review of an LCA is required when the study is not reported with full transparency, i.e. when all data, assumption and decisions made are not reported at the level of detail used in the study. [8] As this study is reported with full transparency, no critical LCA review has been carried out.

2. h Accounts of data, inventory and characterisation

All sections with collected data and or inventory data have been marked with the symbol † next to the heading of the section.

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[6] Data of class III are either calculated using standard emission factors, taken from the literature or estimated from experience (Lindfors L-G. 1995.Op cit . P. 55.

[7] Carlsson A. 1997. *Food Consumption Patterns and theit Influence on Climate Change- greenhouse gas emissions in the life-cycle of tomatoes and carrots consumed in Sweden*. Manuscript submitted to Ambio in January 1997.

[8] Lindfors L-G.1995. Op cit. P. 28.

2.g Characterisation

Characterisation is the step in an LCA when the contributions to each impact category are assessed by qualitative or quantitative methods. In this analysis, Global Warming Potentials (GWPs) were used to characterise the calculated emissions of greenhouse gases. All sections with characterised data have been marked with the symbol © next to the heading of the section. Global Warming Potentials for 20 and 100 years were used and all emissions were supposed to occur at the same instant. The results are expressed as g CO_2 equivalents. The arable land use is expressed in m^2 per capita and year with no further characterisation and the same is the case with the energy requirements, expressed in MJ.

3. Consumed amounts and countries of consumption origin †

The annually consumed amounts of carrots and tomatoes for one person in Sweden are shown in Table 1 together with the countries of consumption origin. The consumption of carrots was 6,8 kg per person and year in 1992-1993 and the corresponding consumption of tomatoes was 7,2 kg.

Table 1: Annual average consumption 1992-1993 of carrots and tomatoes in Sweden. In kg per capita and year according to countries of consumption origin. [9,10]

	Annual consumption, kg* capita^{-1} * year^{-1}	
	Carrots	Tomatoes
Denmark	0,26	0,45
Netherlands	0,28	2,68
Germany	0,03	
Great Britain	0,02	
Italy	0,15	
Spain		2,1
Sweden	6,0	1,7
"Other countries"	0,04	0,25
Total	6,8	7,2

Carrots from the Netherlands, Germany, Great Britain, Italy and "other countries" were mainly imported during the spring and early summer, while Danish carrots were imported during the whole year , see Figure 1.

[9] *Livsmedelskonsumtionen 1990-1993.* 1994. Swedish Board of Agriculture, Jönköping, Rapport 1994:6, 44 p. In Swedish. P. 41 for the total consumed amounts of carrots and tomatoes.

[10] *Marknaden för frukt och grönsaker blommor 1993.* The Swedish Association of Fruit and Vegtetable Distributors, Stockholm, 47 p. In Swedish. P. 13-14 for the imported amounts of tomatoes and p. 20-21 for the imported amounts of carrots. The amounts of carrots and tomatoes originating from Sweden were obtained by subtracting the imported amounts divided by the Swedish population from the consumed amounts.

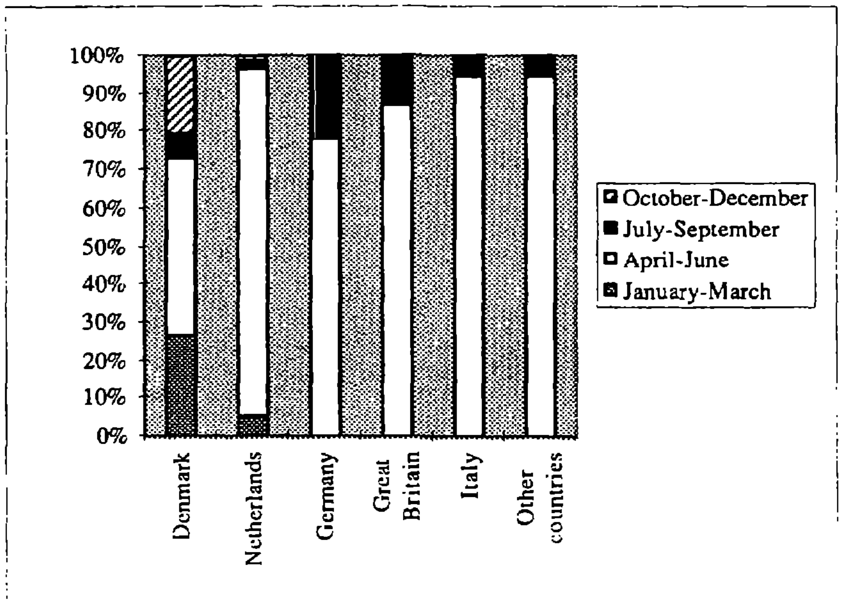

Figure 2: Imported amounts of carrots to Sweden from Denmark, the Netherlands, Germany, Great Britain, Italy and "other countries" (in this case France, Spain and Israel) in 1993. [11] **In relative shares according to the quarters of the year.**

4. Places of consumption origin and place of consumption †

A place needed to be selected within each of the countries of consumption origin from where the transportation distance to the Swedish retailer could be calculated. The first choice was to use information from the interviewees, an easy and straightforward method when the interviewees agreed. When the interviewees did not agree, the size of the area in question was considered. If the size of that area was smaller than the largest Swedish county (98 906 km^2), the capital, or the largest city, within that area was chosen as the location from where the vegetables originated. If the area in question was larger than the largest Swedish county, the co-ordinates of the place from where the products most likely came from were calculated. [12] The last method was used for German carrots and tomatoes and carrots from Sweden.

4.a Denmark

Carrots imported from Denmark come from an area around the bay of Lammefjorden in Sjaelland. [13] [14] [15] Denmark has a total area of 43 093 km^2.. A fairly large locality in proximity to Lammefjorden is Holbaek. *Holbaek* was chosen as the place of consumption origin for Danish carrots.

[11] Statistics Sweden, Foreign Trade, Stockholm, faxed information, 0996.

[12] The co-ordinatess are calculated using the same principles as for weighted averages. The formula is $NX = n_1a_1 + n_2a_2 .... n_m a_m$ where N is the total amount of products produced within that country of consumption origin, X one of the new co-ordinates, n the amount of products produced within a certain area in the country of consumption origin and x the co-ordinates of the main city within that area.

[13] ICA Handlarnas AB- Frukt och Grönt, Helsingborg, Sweden, Palle Carlsson, personal communication, 0196.

[14] Nordisk Transport AB, Helsingborg, Sweden, Raoul Wong, personal communication, 0196.

[15] ASK-centralen AB, Helsingborg, Sweden, Lars Bengtsson, personal communication, 0196.

Tomatoes imported from Denmark come from Sjaelland. [16] In Sjaelland, they are most likely to come from an area close to a locality called Masnedö. [17] Masnedö is located in proximity to Vordingborg. *Vordingborg* was chosen as the place of consumption origin for Danish tomatoes.

4.b Germany

The interviewees did not agree upon any specific location in Germany concerning carrots. [18] [19] Germany covers an area of 356 854 km^2, thus a much larger area than the largest Swedish county. Table 2 contains the necessary information for calculating the co-ordinates of the German carrot consumption origin.

The co-ordinates for the carrot consumption origin are 51^o 18 ' N and 9 ^{o} and 17 ' E. A city close to these co-ordinates is Kassel. *Kassel* was chosen as the place of consumption origin for German carrots.

Table 2: German länder, main cities and the co-ordinates of each main city [20] Carrot harvests in metric tonnes during 1994. [21]

Länder	Main city	Co-ordinates longitude	Co-ordinates latitude	Carrot harvest, tonnes, 1994
Baden-Würtenberg	Stuttgart	49.07 E	8.48 N	13437
Bayern	München	48.13 E	11.58 N	16616
Berlin	Berlin	52.53 E	13.42 N	-
Brandenburg	Potsdam	52.40 E	13.05 N	19697
Bremen	Bremen	53.08 E	8.80 N	-
Hamburg	Hamburg	53.55 E	10.00 N	175
Hessen	Wiesbaden	50.08 E	8.25 N	10429
Mecklenburg-Vorpommern	Schwerin	53.63 E	11.42 N	1370
Niedersachsen	Hannover	52.38 E	9.73 N	66161
Nordrhein-Westfalen	Düsseldorf	51.22 E	6.78 N	44615
Rheinland-Pfaltz	Mainz	50.00 E	8.27 N	44882
Saarland	Saarbrücken	49.25 E	6.97 N	491
Sachsen	Dresden	51.05 E	13.75 N	580
Sachsen-Anhalt	Magdeburg	52.13 E	11.62 N	7081
Schleswig-Holstein	Kiel	54.33 E	10.13 N	18827
Thüringen	Erfurt	50.97 E	11.03 N	0

4.c Great Britain

The area north and north east of London were identified as the main area of origin for British carrots [22] [23]. In this study, the area to the north and north east of

[16] The Swedish Association of Fruit and Vegetable Distributors, Stockholm, Åke Natt och Dag, personal communication, 0895.

[17] Danish Embassy, Department of Trade, Stockholm, Ellen Hansen, personal communication, -95.

[18] ICA Handlarnas AB-Frukt och Grönt , Palle Carlsson, op cit.

[19] Nordisk Transport AB, Raoul Wong, op cit.

[20] Co-ordinates (in degrees and minutes) transformed to decimal numbers.

[21] *Statistical Yearbook for the federal republic of Germany.*. 1995. Federal Statistical Office, Wiesbaden,771 p. In German, Preface, Table of Contents and general Introduction in English. P. 170-171.

[22] ICA Handlarna AB - Frukt och Grönt, Palle Carlsson, op cit.

[23] The Swedish Association of Fruit and Vegetable Distributors, Åke Natt och Dag, op cit.

London were identified as composed of the councils of Essex, Hertfordshire, Bedfordshire, Cambridgeshire, Suffolk and Norfolk. Together these councils cover an area of 19 115 km^2, thus less than the largest Swedish county. *Cambridge* was chosen as the place of consumption origin for British carrots.

4.d Italy

Carrots imported from the Italy come from Sicily and Calabria in the beginning of the year, but towards summer they come from northern Italy (the Po-valley or the area around Choggia). [24] [25] [26] Italy has an area of 301 277 km^2, thus much larger than the largest Swedish county. *Rome* was chosen as the place of consumption origin for Italian carrots because Rome is situated approximately halfway between Sicily and the Po-valley.

4.e Netherlands

The interviewees did not agree upon any specific location in the Netherlands concerning carrot origin. [27] [28] [29] Since the area of the Netherlands is no more than 41 883 km^2, *Amsterdam* was chosen as the place of consumption origin for Dutch carrots.

The interviewees all reported that tomatoes imported from the Netherlands came from an area called the Westland. [30] [31] [32] Westland is located between Rotterdam and the Haag, and belongs to the province of Zuidholland. A locality called *Naaldwijk* in Westland was chosen as the place of consumption origin for Dutch tomatoes.

4.f Spain

Tomatoes imported from Spain come from the areas around Murcia and Almeria on the Spanish mainland, or from the Canary Islands (Gran Canary or Tenerife). [33] [34] An estimation is that 50 % of the tomatoes came from the mainland and the remaining ones from the Canary Islands. [35] The assumption is that half of the tomatoes from the mainland came from Murcia and the other half from Almeria.

The place of consumption origin for Spanish tomatoes from the mainland is considered to be *halfway between Murcia and Almeria* (125 km to the south of Murcia on the way to Almeria).

The Canary Islands occupies an area of 7 4242 km and a large city within that area is *Las Palmas* which was chosen as the place of consumption origin for Spanish tomatoes from the Canary Islands.

4.g Sweden

Table 3 contains the necessary information for calculating the co-ordinates of the consumption origin for Swedish carrots and tomatoes.

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[24] ICA Handlarna AB - Frukt och Grönt, Palle Carlsson, op cit.
[25] Nordisk Transport AB, Raoul Wong, op cit.
[26] ASK-centralen AB, Lars Bengtsson, op cit.
[27] ICA Handlarna AB - Frukt och Grönt, Pallle Carlsson, op cit.
[28] Nordisk Transport AB, Raoul Wong, op cit.
[29] ASK-centralen AB, Lars Bengtsson, op cit.
[30] Nordisk Transport AB, Raoul Wong, op cit.
[31] ASK-centralen AB, Lars Bengtsson, op cit.
[32] The Swedish Association of Fruit and Vegetable Distributors, Åke natt och Dag, op cit.
[33] ASK-centralen AB, Lars bengtsson, op cit.
[34] The Swedish Association of Fruit and Vegetable Distributors, Åke Natt och Dag, op cit.
[35] Spanish Embassy , Commercial section, Stockholm, personal communication, -95.

Table 3: Swedish counties, main cities (seat of the county governor) and the co-ordinates in the Swedish national grid system for each main city. Tomato and carrot harvests in metric tonnes during 1993. [36]

County	Main city	Co-ordinates, x	Co-ordinates, y	Carrot harvest, tonnes, 1993	Tomato harvest, tonnes, 1993
Blekinge	Karlskrona	6212867	1349193	120	1219
Gotland	Visby	6392136	1649285	20995	398
Gävleborgs	Gävle	6730396	1576190	135	10
Göteborg och Bohus	Göteborg	6392126	1237635	37	407
Halland	Halmstad	6286694	1319569	10297	1098
Jämtland	Östersund	6993737	1356709	52	102
Jönköping	Jönköping	6390905	1308865	36	257
Kalmar	Kalmar	6284024	1533539	915	383
Kopparbergs	Falun	6720185	1492643	187	135
Kristianstad	Kristianstad	6211895	1396376	10800	4253
Kronoberg	Växsjö	6290811	1324030	22	20
Malmöhus	Malmö	6166702	1323635	12470	7766
Norrbotten	Luleå	7291417	1793324	76	233
Skaraborgs	Mariestad	6511018	1385736	3074	103
Stockholm	Stockholm	6561046	1433504	41	292
Södermanland	Nyköping	6497805	1401802	96	37
Uppsala	Uppsala	6637069	1602835	176	48
Värmland	Karlstad	6587324	1369282	207	66
Västerbotten	Umeå	7087706	1719014	55	242
Västernorrlands	Härnösand	6948572	1609238	102	138
Västmanland	Västerås	6594832	1389588	166	143
Älvsborgs	Vänersborg	6465118	1256212	44	219
Örebro	Örebro	6572817	1466169	11953	543
Östergötland	Linköping	6475295	1490712	8322	777

The co-ordinates for the carrot consumption origin in Sweden are 6363426 and 1464147 in the national grid system. Holsbybrunn, close to Vetlanda (57° 26' N, 15° 05' E) was chosen as the place of consumption origin for Swedish carrots.

The co-ordinates for tomato consumption origin in Sweden are 6284462 and 1378703 in the national grid system. Strömsnäsbruk, with the co-ordinates 56° 35' N, 13° 45' E was chosen as the place of consumption origin for Swedish tomatoes.

4. e Other countries

Carrots were imported from six "other countries" (France, Hungary, Israel, Norway, Poland, Spain and USA) in 1992-1993. No calculation, or evaluation, of the places of consumption origin within these countries was made.

Tomatoes were imported from 27 "other countries" in 1992. These countries were: Belgium, Bulgaria, Canada, China, Egypt, Estonia, Finland, France, Germany, Greece, Island, Israel, Italy, Yugoslavia, Latvia, Lithuania, Morocco, Niger, Norway, Poland, Portugal, Romania, Switzerland, Turkey, USA, Zimbabwe and the Dominican Republic. No calculation, or evaluation, of the places of consumption origin within these countries was made.

[36] *The 1994 Horticultural Census concerning 1993.* 1994. Statistics Sweden, Örebro, Sweden, J 10 SM 9403, 120 p. In Swedish. P. 62-68 and 88. National Land Survey of Sweden, Gävle, personal communication for the co-ordinates in the national grid system.

4.f Place of consumption

The place of consumption is considered to be located at Pålsboda, which is close to the centre of population mass in Sweden. [37] Pålsboda has the co-ordinates 59° 4' N, 15° 21' E and is located in the county of Närke.

5. Yields †

Information on the yields of carrots and tomatoes are compiled in Table 4.

Table 4: Yields of carrots and tomatoes in Denmark, the Netherlands, Germany, Great Britain, Italy, Spain, Sweden and "other countries". In kg per m^2 and year.

Country	Region	Year	Yields, $kg* m^{-2} *year^{-1}$		Production system for tomatoes
			Carrots	Tomatoes	
Denmark		1987	5,43 [38]	28,56 [39]	under glass
Netherlands		1994/ 1991	6,19 [40]	40,52 [41]	under glass
Germany		1994	4,26 [42]		
Great Britain		1994	4,76 [43]		
Italy		1994	4,18 [44]		
Spain	Murcia	1992		10,65 [45]	open ground
	Almeria	1992		9,14 [46]	open ground
continued...	Canary Islands	1992		8,05 [47]	open ground

[37] *Sveriges Nationalatlas -befolkningsdelen*. 1991. Sveriges Nationalatlas förlag, 176 p..In Swedish. The mean centre of population mass for a specific area is defined as the point to which all the inhabitants could simultaneously travel while covering as short total distance as possible. The distance is measured as the crow flies. A population centre called Svennevad in the district of Hallsberg was the mean centre of population in Sweden 1990. Its co-ordinates are 6541/1477 in the National Grid system or 15°11' E, 59° 2' S. Pålsboda is situated about 7 km from Svennevad.

[38] *Agricultural Statistics 1987*. 1988. Statistics Denmark, Copenhagen, 341 p..In Danish. P. 181.

[39] *Agricultural Statistics 1987*. 1988. Op cit. P.182.

[40] *FAO Yearbook: Production 1994*. 1995. Food and Agricultural Organisation, Rome, Volume 48, 243 p. Table 62.

[41] *Tuinbouwcijfers 1993. Statistical data on horticulture in the Netherlands*. Landbouw-economisch instituut (LEI-DLO) and Centraal bureau voor de statistiek, Den Haag, 164 p. In Dutch, and English Translation of the table of contents and the list of tables is available on request. Table 82-h for trade production 1991 and Table 47-a for area under glass 1991.

[42] *Statistical Yearbook for the federal republic of Germany.*. 1995.Op cit. P. 169.

[43] *FAO Yearbook: Production 1994*. 1995. Op cit. Table 62.

[44] *FAO Yearbook: Production 1994*. 1995. Op cit. Table 62.

[45] *Anuario de estadi'stica agraria 1992*. 1994. Ministerio de agricultura, pesca y alimentacion, Madrid 679 p. In Spanish. P. 233 for protected and irrigated tomatoes.

[46] *Anuario de estadi'stica agraria 1992*. 1994.Op cit.

[47] *Anuario de estadi'stica agraria 1992*. 1994.Op cit.

Country	Region	Year	Yields, kg* m2 *year-1		Production system for tomatoes
			Carrots	Tomatoes	
Sweden		1993	4,36 [48]	29,60 [49]	under glass
"Other countries"		-	4,18 [50]	8,05 [51]	open ground

6. Handling and losses ☦

4.a Handling of vegetables produced in Sweden

Vegetables produced in Sweden may be handled by no, or several, middlemen on their way from the producer to the retailer. The different handling options are shown in Figure 3. The vegetables may be delivered directly from the producer to the retailer or by passing through one or several middlemen. A local wholesaler may handle the vegetable before they reach the retailer. A more complex option is when the vegetables are transported from the producer to a wholesaler in Helsingborg [52] from where they are taken to a local wholesaler before reaching the retailer. The vegetables may also be transported from the producer to a wholesaler in Helsingborg and then directly to the retailer. All options may, or may not, include passing through a farmers co-operative (collector) situated closely to the producer. At all these "stations" losses are likely to occur.

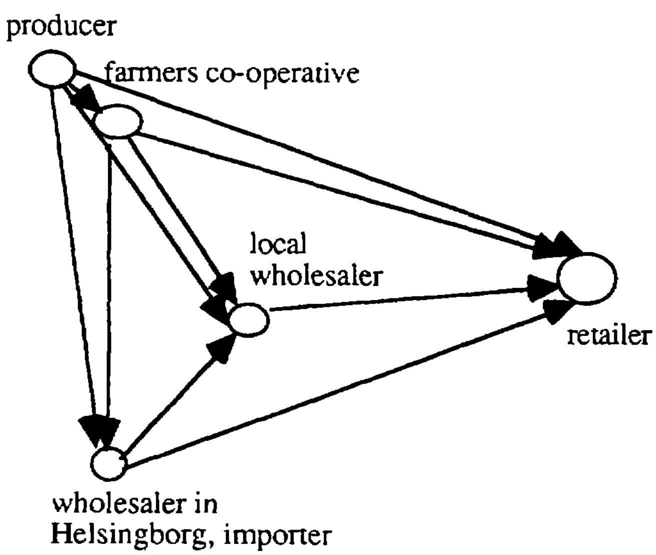

Figure 3: Schematic structure of handling options for Swedish produced vegetables.

[48] *Trädgårdsodlingen i Sverige 1984-1993-en statistik sammanställning.* 1995. Swedish University of Agricultural Sciences, Alnarp, SLU/Info Trädgård rapporter 384, 39 p. In Swedish. Table 17.

[49] *Trädgårdsodlingen i Sverige 1984-1993-en statistik sammanställning.* 1995. Op cit. Table 10.

[50] Assumed to be the same as in Italy.

[51] Assumed to be the same as in the Canary Islands.

[52] In Helsingborg there are two very large establishments where both imported and Swedish produced vegetables are handled. Vegetable production in Sweden is concentrated to the southern part of the country and imported vegetables mostly come by lorry from the south. Either the lorries enter Sweden in Helsingborg from Helsingör in Denmark. They may also enter Sweden in Ystad (coming from Poland) or in Trelleborg (coming from Germany).

4.b Handling of vegetables produced in other countries than Sweden

Vegetables produced abroad and imported to Sweden are generally collected by specialised firms (collectors) in the countries of consumption origin. These firms are generally located close to the producers. The vegetables are generally unloaded at a Swedish importer in Helsingborg, Malmö, Stockholm or Gothenburg, reloaded and transported to a local wholesaler from where they are again transported to the Swedish retailer.

4.c Losses

Losses of products occur in the handling chain when products with inferior quality are sorted out. No published relevant information on losses in the handling chain was available. Representatives of the middlemen and the producers could, however, make rough estimates of losses at the different "stations" during handling. Information on losses in the handling chain is compiled in Table 5.

Table 5: Losses of carrots and tomatoes produced in Denmark, Germany, Great Britain, Italy, the Netherlands, Spain, Sweden and "other countries". Danish and Swedish carrots in long-term storage, German, British, Italian and Dutch carrots in short term storage.

Vegetable	Country of consumption origin	Losses of the amounts harvested/delivered to the different "stations". In %.				
		Producer	Collector,	Importer [53]	Local [54] whole saler	Total losses
Carrots	Denmark	21 [55]	3,3 [56]	0,5	2	25
	Germany	5 [57]	3,3 [58]	0,5	2	10
	Great Britain	5 [59]	3,3 [60]	0,5	2	10
	Italy	5 [61]	3,3 [62]	0,5	2	10
	Netherlands	5 [63]	3,3 [64]	0,5	2	10
	Sweden	0 [65]	17,5 [66]	0,5	2	20
	"Other countries"					25 [67]

continued...

[53] The Swedish Association of Fruit and Vegetable Distributors, Åke Natt och Dag, op cit, 0995.

[54] The Swedish Association of Fruit and Vegetable Distributors, Åke Natt och Dag, op cit, 0995.

[55] *Agricultural Statistics 1987*. 1988. Op cit. P. 181.

[56] GASA Odense, Karsten Egledal, personal communication, 0496.. Estimation concerning all vegetables. GASA Odense is an organisation for Danish wholesalers. The estimation is very rough and it was apparent that the interviewee had never been asked such a question before

[57] Gotlands Trädgårdsprodukter, Visby, Freddy Hägglund, personal communication, 0496. Mr Hägglund estimated that about 10 % of carrots in short term storage are discarded before reaching the retailer. I have assumed that the total losses of German carrots in short-term storage are of the same order. Given losses at the collector, the importer and the wholesaler of 3,25 %, 0,5,% and 2 % respectively, the losses at the producer must be about 5 %.

[58] Assumed to be the same as in Denmark

[59] Assumed to be the same as for German carrots

[60] Assumed to be the same as in Denmark

[61] Assumed to be the same as for German carrots

[62] Assumed to be the same as in Denmark

[63] Assumed to be the same as for German carrots

[64] Assumed to be the same as in Denmark

[65] Assumed to be delivered directly from the producer to the collector, therefore no losses.

[66] Gotlands Trädgårdsprodukter, Freddy Hägglund, op cit. 15-20 % of the carrots in long-term storage are discarded and usually used for fodder.

[67] Assumed to be the same as for Danish carrots.

Vegetable	Country of consumption origin	Losses of the amounts harvested/delivered to the different "stations". In %.				
		Producer	Collector.	Importer	Local whole saler	Total losses
Tomatoes	Denmark	0 [68]	3,3 [69]	0,5	2	5,7
	Netherlands	1 [70]	1,8 [71]	0,5	2	5,2
	Spain	0	10 [72]	0,5	2	12
	Sweden	1 [73]	0 [74]	0,5	2	3,5
	"Other countries"					12 [75]

7. Arable land use for the consumed amounts of carrots and tomatoes ©

The method for calculating the arable land use (L_a) in m^2*capita^{-1} for the consumed amounts of carrots and tomatoes is:

$$L_a = m_r / [(1 - l_p / 100) * h]$$

where

m_r= Consumed amounts, kg* capita^{-1} * year^{-1} (Table 1).

l_p= Losses of products, % (Table 5).

h=Yields, kg*m^{-2} *year $^{-1}$ (Table 4).

The arable land use for the consumed amounts of carrots and tomatoes in Sweden is shown in Table 6.

68 *Agricultural Statistics 1987*. 1988.Op cit.P. 182.
69 GASA Odense, Karsten Egledal, op cit.
70 Landbouw-economisch instituut (LEI-DLO), Den Haag, Jo Wijnands, personal communication, 0496.
71 Product Board for Fruit and Vegetables, Den Haag, Miriam de Wit, personal communication, 0596. Data for 1995.
72 Bony Exportacion, Las Palmas, Pepin Garcia. personal communication, 0796.
73 Trädgårdsutveckling AB, Alnarp, Torbjörn Hansson, personal communication, 0496.
74 Odlarlaget i Helsingborg, Stefan Dahl, , personal communication, 0496. The tomatoes are commonly sorted and packed by the producer. The approximate handling time at a collector such as Odlarlaget is 0.5 hours. Odlarlaget handles approximately 40 % of the Swedish tomatoes. The same approximation for losses was done by Sydgrönt AB,Malmö, Rolf Andersson, personal communication. Sydgrönt AB handles about 25 % of all Swedish tomatoes.
75 Assumed to be the same as for Spanish tomatoes.

Table 6: Arable land use in m^2 per capita according to country of consumption origin for the consumed amounts of carrots and tomatoes in Sweden. [76]

Vegetable	Country of consumption origin	Arable land use, $m^2 * capita^{-1}$
Carrots	Denmark	0,062
	Germany	0,051
	Great Britain	0,008
	Italy	0,005
	Netherlands	0,039
	Sweden	1,658
	"Other countries"	0,014
	Total carrots	1,84
Tomatoes	Denmark	0,017
	Netherlands	0,070
	Spain- Murcia	0,055
	Spain- Almeria	0,064
	Spain-Canaries	0,15
	Sweden	0,061
	"Other countries"	0,037
	Total tomatoes	0,45

8. Distances, modes of transport and transportation time †

Table 7-12 shows the distances from the places of consumption origin to place of consumption. The Swedish importer is assumed to be located in Ljungby, 56 ° 49 ' N, 13 ' 55 ° E [77] and the local wholesaler in Arboga which is close to Eskilstuna (59° 22 ' N, 16° 31' E). [78] Table 7-12 also shows the transportation modes (lorries, ferries, ships and planes) and the transportation times. Information concerning transportation modes has been collected from Swedish firms importing and marketing vegetables such as ASK-centralen, ICA frukt-och grönt and Nordisk Transport AB. The transportation times were obtained by dividing the number of km by 70 km per hour for lorry transportation. Transportation times with plane, ferry and ship were obtained from several sources as indicated in Table 7-12

[76] Consumed amounts in Table 1, losses in Table 5 and yields in Table 4.

[77] According to ASK centralen AB, Hans Jönson, personal communication, 0995 and ICA Handlarnas AB – Frukt och Grönt, Palle Carlsson personal communication, 0995, about 65 % of the imported vegetables are unloaded in Helsingborg, 5 % in Malmö, 10 % in Gothenburg and 20 % in Stockholm. These relative shares were used for weighting the co-ordinates of Malmö, Helsingborg, Stockholm and Gothenburg. The weighted co-ordinate is located near Ljungby.

[78] A retailer in Pålsboda will receive food deliveries from wholesalers in Västerås or Örebro according to information from the four largest retailing blocks in Sweden (ICA, D-gruppen and Axel Johnson and Konsum). ICA, D-gruppen and Axel Johnson have wholesalers in Örebro while Konsum has a wholesaler in Västerås. The weighted co-ordinates of Örebro and Västerås (weighting with the appreciated market shares in Table 13) is situated close to Arboga.

8.a Denmark

Table 7: Transportation from the places of consumption origin in Denmark to the place of consumption in Sweden. Distances, transportation modes and times for carrots and tomatoes [79] [80] [81]

Vegetable	Route	km	transportation mode	hours
Carrots	Holbaek-Helsingör	201	lorry	2,9
	Helsingör-Helsingborg	4	ferry	1
	Helsingborg-Ljungby	128	lorry	2,3
	Ljungby-Arboga	354	lorry	6,1
	Arboga-Pålsboda	70	lorry	1
	Total carrots	757		13
Tomatoes	Vordingborg-Helsingör	138	lorry	2
	Helsingör-Helsingborg	4	ferry	1
	Helsingborg-Ljungby	128	lorry	2,3
	Ljungby-Arboga	354	lorry	6,1
	Arboga-Pålsboda	70	lorry	1
	Total tomatoes	694		12

[79] *Vägavstånd Transportatlas för Sverige*. 1981. Svenska Åkeriförbundet, Danderyd, Sweden, 312 p. In Swedish. For road distances in Sweden only.
[80] Distances from Vording borg and Holback to Helsingör measured on a map.
[81] The ferry from Helsingör to Helsingborg usually takes 0,5 hours, but with loading and unloading included I have estimated the total time to 1 hour.

8.b Germany

Table 8: Transportation from the places of consumption origin in Germany to the place of consumption in Sweden. Distances, transportation modes and times for carrots. [82] [83] [84]

Vegetable	Route	km	transportation mode	hours
Carrots	Kassel-Travemünde	390	lorry	5,6
	Travemünde-Trelleborg	218	ferry	7
	Trelleborg-Ljungby	196	lorry	3
	Ljungby-Arboga	354	lorry	6,1
	Arboga-Pålsboda	70	lorry	1
	Total carrots	1228		22

8.c Great Britain

Table 9: Transportation from the places of consumption origin in Great Britain to the place of consumption in Sweden. Distances, transportation modes and times for carrots. [85] [86]

Vegetable	Route	km	transportation mode	hours
Carrots	Cambridge-Ipswich	75	lorry	1,1
	Ipswich-Gothenburg	998	ferry	28
	Gothenburg-Ljungby	202	lorry	3
	Ljungby-Arboga	354	lorry	6,1
	Arboga-Pålsboda	70	lorry	1
	Total carrots	1699		39

[82] *Vägavstånd Transportatlas för Sverige*. 1981. Op cit.

[83] *Eurotour Europäische Straßenentfernungen*. (database). Verkehrs verlag J Fischer, Düsseldorf, Germany. For road distances within Western Europe except Scandinavia and the UK.

[84] TT-line AB, Trelleborg, personal communication with the information desk, 1095. For the distance and time from Travemünde to Trelleborg. TT-line is a shipping company with regular traffic between Germany and Sweden.

[85] *Vägavstånd Transportatlas för Sverige*. 1981. Op cit. Road distance from Cambridge to Ipswhich measured on a map.

[86] *Reed's Marine Distance Tables*. 1992. Thomas Reed Publications Limited, Surrey, 203 p. P. 53 for the distance in nautical miles between Ipswich and Gothenburg.

8.d Italy

Table 10: Transportation from the places of consumption origin in Italy to the place of consumption in Sweden. Distances, transportation modes and times for carrots. [87]

Vegetable	Route	km	transportation mode	hours
Carrots	Rome-Travemünde	1869	lorry	26,7
	Travemünde-Trelleborg	218	ferry	7
	Trelleborg-Ljungby	196	lorry	3
	Ljungby-Arboga	354	lorry	6,1
	Arboga-Påslboda	70	lorry	1
	Total carrots	2707		44

8.e The Netherlands

Table 11: Transportation from the places of consumption origin in the Netherlands to the place of consumption in Sweden. Distances, transportation modes and times for carrots and tomatoes. [88]

Vegetable	Route	km	transportation mode	hours
Carrots	Amsterdam-Travemünde	551	lorry	7,9
	Travemünde-Trelleborg	218	ferry	7
	Trelleborg-Ljungby	196	lorry	3
	Ljungby-Arboga	354	lorry	6,1
	Arboga-Pålsboda	70	lorry	1
	Total carrots	1389		25
	Naaldwijk -Travemünde	604	lorry	9
	Travemünde-Trelleborg	218	ferry	7
	Trelleborg-Ljungby	196	lorry	3
	Ljungby-Arboga	354	lorry	5
	Arboga-Pålsboda	70	lorry	1
	Total tomatoes	1442		24

[87] *Vägavstånd Transportatlas för Sverige*. 1981. Op cit. *Eurotour Europäische StraBenentfernungen.* (database). Op cit. TT-line, op cit.

[88] *Vägavstånd Transportatlas för Sverige*. 1981. Op cit. *Eurotour Europäische StraBenentfernungen.* (database). Op cit. TT-line, op cit.

8.f Spain

Table 12: Transportation from the places of consumption origin in Spain to the place of consumption in Sweden. Distances, transportation modes and times for tomatoes. Three different routes: by truck from the mainland, by ship from the Canary Islands and by plane from the Canary Islands. [89 90 91]

Route	Spanish mainland			Canaries-boat			Canaries-plane		
	km	**transpor-tation mode**	**hours**	**km**	**transpor-tation mode**	**hours**	**km**	**transpor-tation mode**	**hours**
Almeria/Murcia -Travemünde	2567	lorry	36,7						
Las Palmas-Rotterdam				3278	boat	90			
Las Palmas – Stockholm							4350	plane	8
Rotterdam–Travemünde				621	lorry	8,9			
Travemünde-Trelleborg	218	ferry	7	218	ferry	7			
Trelleborg-Ljungby	196	lorry	2,8	196	lorry	2,8			
Ljungby-Arboga	354	lorry	5,1	354	lorry	5,1			
Stockholm-Arboga							158	lorry	2,3
Arboga - Pålsboda	70	lorry	1	70	lorry	1	70	lorry	1
Total tomatoes	3405		53	4737		115	4578		12

8.g Sweden

No estimations about transportation distances from the Swedish places of consumption origin to the place of consumption in Sweden were found, nor any method describing how such estimations could be made. Therefore, a method was developed to this end. The method combines data on relative market shares with information on options effectively chosen in the handling chain. Further, the method includes assumptions about the locations of producers, retailers and middlemen and information about road distances.

The method for calculating the average distance required for transporting Swedish vegetables from the place of consumption origin to the place of consumption (or any other Swedish produced food) (L_{ts}) in km is:

$$L_{ts} = \sum_{i=a}^{e} S_{hwi} * l_{thi}$$

where

[89] *Vägavstånd Transportatlas för Sverige*. 1981. Op cit. *Eurotour Europäische Straßenentfernungen*. (database). Op cit. TT-line, op cit. *Reed's Marine Distance Tables*. 1992. Op cit.
[90] Cool Carriers, Danderyd, Svante Hellberg, faxed information, 0796. For the time needed for a ship to travel from Las-Palmas to Rotterdam. A ship may travel with a speed of about 21 knots per hour. I have calculated the time needed for shipping from Las Palmas to Rotterdam on the basis of a speed of 20 knots per hour.
[91] Scandinavian Airline System (SAS), Flight Support, Stockholm, Lena Wålinder, personal communication, -96. For the distance by plane from Las Palmas to Stockholm as the crow flies. The real flight distance may be 4 400 km.

i = the different handling options a to e.

S_{hwi} = the assumed share of vegetables handled according to handling option i. (Table 14)

l_{thi} = the calculated road distance for handling option i (km) (Table 16)

S_{hwi} is calculated as:

$$S_{hwi} = \sum_{k=1}^{4} S_{hi,k} * S_{mwk}$$

where

k = the different retailing blocks 1 to 4.

i =the different handling options a to e.

$S_{hi,k}$= share of vegetables handled according to handling option i in retailing block k. (Table 14)

S_{mwk} = assumed market shares for retailing block k. (Table 13)

S_{mwk} is calculated as:

$$S_{mwk} = S_{mk} / \sum_{k=1}^{4} S_{mk}$$

where

k = the different retailing blocks 1 to 4.

S_{mk}=market share for retailing block k. (Table 13)

l_{thi} is calculated as (km):

$$l_{thi} = \sum_{q=1}^{n} l_{tq}$$

q= the number of possible transportation distances

l_{tq}= road distances to and from the consumption origins, the middlemen and the place of consumption (km) (Table 15).

Four retailing blocks dominate the Swedish retailing sector with altogether 90 % of the total market share. The market shares, as well as the assumed market shares of these four blocks are shown in Table 13.

Table 13: Market shares and assumed market shares of the four largest retailing blocks in Sweden as an average of 1992–1993.

	Market share as an average of 1992-1993 [92]	Assumed market share as an average of 1992-1993
ICA handlarna	0,44	0,48
Konsum exc. OK	0,26	0,28
Axel Johnson AB (Åhlens Hemköp och B&W)	0,05	0,05
D-gruppen (Vivo-Favör)	0,16	0,18
Other	0,10	
Total	1	1

Table 14 shows the shares of vegetables handled according to different options. The options whereby the vegetables are, or are not, handled by a farmers co-operative are not included in Table 14. "Närodlat" is only relevant for Hemköp in Axel Johnson AB. "Närodlat" means that the products come directly from the producer to the retailer and that the producer is not further away from the retailer than 50 km. [93] Table 14 also shows the assumed shares of Swedish produced vegetables handled according to different handling options.

Table 14: Shares of vegetables handled according to different handling options. According to retailing block. Assumed shares of vegetables handled according to different handling options.

	Shares of vegetables handled according to different handling options				
	producer-retailer	producer-local wholesaler-retailer	producer-big wholesaler in Helsingborg-local wholesaler-retailer	producer-big wholesaler in Helsingborg-retailer	Närodlat
ICA handlarna [94]	0	0,30-0,40	0,55-0,65	0,06–0,07	0
Konsum [95]	0,02	0,23	0,75	0	0
D-gruppen [96]	0.10	0,10	0,75	0,05	0
Axel Johnson [97]	0	0,50	0,35	0	0,15
Assumed shares of vegetables handled according to different handling options	0,02	0,28	0,65	0,04	0,01

[92] The Swedish Wholesale and Retail Research Institute, Stockholm, faxed information, 0496.
[93] Hemköpskedjan AB, Falun, Sweden, Sverker Renius, personal communication, 0496.
[94] ICA Handlarnas AB- Frukt och Grönt, Roger Jonson, personal communication, 0496.
[95] AB Goman produkter, Stockholm, Sweden, Sten Johansson, personal communication, 0496.
[96] ASK-centralen AB, Helsingborg, Sweden, Einar Sjöstedt, personal communication, 0496.
[97] Hemköp AB, Sverker Renius,op cit.

Table 14 shows that most vegetables are handled by several middlemen before reaching the retailer, which, in this analysis, is the same as the place of consumption.

Road distances between the consumption origins (Holsbybrunn and Strömsnäsbruk), the middlemen (Helsingborg and Arboga) and the place of consumption (Pålsboda) are shown in Table 15 (below).

Table 15: Road distances to and from the consumption origins, the middlemen and the place of consumption. Carrots and tomatoes produced in Sweden. [98]

From	To	km
Holsbybrunn	Pålsboda	207
Holsbybrunn	Arboga	277
Holsbybrunn	Helsingborg	247
Strömsnäsbruk	Pålsboda	331
Strömsnäsbruk	Arboga	389
Strömsnäsbruk	Helsingborg	95
Arboga	Pålsboda	70
Helsingborg	Arboga	482
Helsingborg	Pålsboda	427
Närodlat	Pålsboda	50

The calculated road distances for the different handling options are shown in Table 16 (below)

Table 16: Calculated road distances for the different handling options. Carrots and tomatoes produced in Sweden

Vegetable	Handling option	km
Carrots	producer-retailer	207
	producer–retailer ("närodlat")	50
	producer-local wholesaler-retailer	347
	producer-big wholesaler in Helsingborg-local wholesaler-retailer	799
	producer- big wholesaler in Helsingborg-retailer	674
Tomatoes	producer-retailer	331
	producer–retailer ("närodlat")	50
	producer-local wholesaler-retailer	459
	producer-big wholesaler in Helsingborg-local wholesaler-retailer	647
	producer- big wholesaler in Helsingborg-retailer	522

The average distance required for transporting carrots from the place of consumption origin to the place of consumption (L_{ts}) is 650 km. The time required for this transportation is 9,3 hours if a lorry with an average speed of 70 km per hour is used.

The average distance required for transporting tomatoes from the place of consumption origin to the place of consumption (L_{ts}) is 576 km. The time required for this transportation is 8,2 hours if a lorry with an average speed of 70 km per hour is used.

98 *Vägavstånd Transportatlas för Sverige*. 1981. Op cit.

8.e "Other countries"

The Weighted Average Source Distance for carrots imported from "other countries is 2 226 km. [99] This is about the same distance as from Lisbon in Portugal to Stockholm as the crow flies. The time required for this transportation is 39 hours if a lorry with an average speed of 70 km per hour is used.

The Weighted Average Source Distance for tomatoes imported from "other countries" is 1399 km. This is about the same as the distance between Paris and Stockholm as the crow flies. The time required for this transportation is 20 hours if a lorry with an average speed of 70 km per hour is used.

9. Energy requirements for transportation †

9.a Lorries

Tillman [100] recommends energy requirements factors for lorries without transport refrigeration equipment of 0,97 MJ per tonne-km for long-range transports, 1,81 MJ per tonne-km for regional distribution and 2,35 MJ per tonne-km. These figures include pre-combustion energy requirements. The loading capacity of the lorries are assumed only to be used to 50 %.

The assumption in this study is that long-range transports are carried out with lorries with a total weight of 40–50 tonnes and a loading capacity of 25–30 tonnes, regional distribution with lorries with a total weight of 24 tonnes and a loading capacity of 12 tonnes and city distribution with lorries of a total weight of 14 tonnes and a loading capacity of about 7 tonnes. The definition of long-range transports is that the transportation distance exceeds 100 km. The corresponding definition of regional distribution is that the transportation distance is 50-100 km, and for city distribution the transportation distance is below 50 km. [101]

Fuel requirements for running the transport refrigeration equipment are reported to be 1.5 litres of diesel per hour for the lorry itself and another 2.5 litres per hour for the trailer. [102]

The energy content of one litre of diesel is 42,5 MJ including pre-combustion requirements. [103] Therefore the transport refrigeration equipment in a lorry with a trailer need 170 MJ per hour and the same equipment in a lorry without a trailer need 64 MJ per hour. The energy requirements for the transport refrigeration equipment in a lorry with a trailer (used for long range transports) may be 0.16 MJ per tonne-km if the lorry is loaded to 50 % of its capacity (15 tonnes) and travels with an average speed of 70 km per hour. The energy requirements for the transport refrigeration equipment in a lorry without a trailer (used for regional distribution) may be 0.18 MJ per tonne-km if the lorry is loaded to 50 % of its capacity (6 tonnes) and travels with an average speed of 60 km per hour. The energy requirements for the transport refrigeration equipment in a lorry without a trailer used for city distribution may be 0.46 MJ per tonne-km if the lorry is loaded to 50 % of its capacity (3.5 tonnes) and

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[99] Weighted Average Source Distances, WASDs, are calculated by weighting the distances between places of consumption origin and the place of consumption with the consumed amounts from the respective places of consumption origin. The method is further explained in Carlsson A. 1996, Weighted Average Source Points and Distances for Consumption Origin–Tools for Environmental Impact Analysis ?, accepted in *Ecological Economics* in January 1997.

[100] Tillman A-M. 1994.*Godstransporter i livscykelanalys Schablonvärden för energianvändning och emissioner*. Chalmers University of Technology, Technical Environmental Planning, Gothenburg, Rapport 1994:1, 5 p. In Swedish. P. 2.

[101] This assumption has partly been based on an interview with Frigoscandia AB, Helsingborg, Frank Möller, personal communication, 0995. When the transportation distance exceeds 100 km, lorries with a loading capacity of 25-30 tonnes are used. When the transportation distance is less than 100 km, lorries with a loading capacity of 7 tonnes are used.

[102] Frigoscandia AB, Helsingborg, Frank Möller, op cit.

[103] Stout B.A. (Editor-in-Chief) and Fluck R.C (Editor). 1992. *Energy in World Agriculture:Energy in Farm Production*. Volume 6, Elsevier, 367 p. P 19. The energy content in one liter of diesel is reported to be 38,66 MJ. I have added 10 % to that amount in oder to include the pre-combustion energy requirements.

travels with an average speed is 40 km per hour. If the lorry is without load, the refrigeration equipment is not used, and no fuel for this equipment is required.

Table 17 contains information about energy requirements for transportation with lorries including the fuel needed for running the transport refrigeration equipment included.

Table 17: Energy requirements for transportation with lorries. Including fuel-requirements for running the transportation refrigeration equipment. Including pre-combustion energy requirements. Long-range transportation by lorries with trailers (loading capacity 30 tonnes), regional distribution with medium weight lorries (loading capacity 12 tonnes) and city distribution by lorries with a loading capacity of 7 tonnes. The loading capacity is assumed to be used to 50 % in all examples.

	Long range distribution	Regional distribution	City distribution
Energy requirements including energy requirements for transport refrigeration equipment. $MJ*kg^{-1}*km^{-1}$	0,00113	0,00199	0,00281

9.b Ships and ferries

Tillman, [104] recommends energy requirements of 0,5 MJ per tonne-km for ships in coastal traffic, 0,19 MJ per tonne-km for ocean-going ships and 0,12 MJ per tonne-km for tankers. The figures do not include additional fuel requirements for running the transport refrigeration equipment but include pre-combustion energy requirements.

The energy needed for transports with ships from the Canary Islands to Rotterdam including the energy needed for running the transport refrigeration equipment is reported to 0,14 MJ per ton km. [105]

The energy requirements for running the transport refrigeration equipment only in a ship travelling from the Canary Islands to Rotterdam has been estimated to 0,0316 MJ per tonne-km. [106] When pre-combustion energy requirements are included, the energy requirements are 0,0348 MJ per tonne-km. If those energy requirements are added to the estimated energy requirements for tankers reported by Tillman, [107] the total energy requirements are 0,15 MJ per tonne-km.

Table 18 contains information about the energy requirements for transportation with ships and ferries excluding and including the fuel needed for running the transport refrigeration equipment.

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[104] Tillman A-M. 1994.Op cit. P. 2.

[105] *Mat och Transporter– en studie i energi användning*. 1994. Swedish Society for Nature Conservation, Stockholm, 27 p. P. 19.

[106] Cool Carriers, Danderyd, Svante Hellberg, op cit.

[107] Tillman A–M. 1994. Op cit.

Table 18: Energy requirements for transportation with ships. Excluding and including fuel-requirements for running the transportation refrigeration equipment . Including pre-combustion energy requirements.

	Coastal traffic	Ocean going ships	Tanker
Energy requirements excluding energy requirements for transport refrigeration equipment. $MJ*kg^{-1}*km^{-1}$	0,00050	0,00019	0,00012
Energy requirements including energy requirements for transport refrigeration equipment. $MJ*kg^{-1}*km^{-1}$	no data [108]	no data	0,00015

9.c Plane

The energy requirements for transporting tomatoes from the Canary Islands to Stockholm by plane were reported to 12,5 kWh per kg. [109] Since the distance from the Canary Islands to Stockholm is about 4 350 km (see Table 12), the energy requirements are 10,3 MJ $*kg^{-1}*km^{-1}$. With a pre-combustion supplement of 10 %, the energy requirements are about 0,011 MJ $*kg^{-1}*km^{-1}$.

10. Energy requirements for transporting the consumed amounts of carrots and tomatoes †

The transported amounts of carrots and tomatoes are shown in Table 19 and Table 20.

Table 19. Transported amounts of carrots. In kg per capita and year. [110]

Country of consumption origin [111]	Leaving the wholesaler in Sweden	Leaving the importer in Sweden	Leaving the collector in the country of consumption origin	Leaving the producer at the place of consumption origin
Denmark	0,26	0,27	0,27	0,28
Netherlands	0,28	0,29	0,29	0,30
Germany	0,03	0,03	0,03	0,03
Great Britain	0,02	0,02	0,02	0,02
Italy	0,15	0,15	0,15	0,15
Sweden	6,00	6,12	6,15	7,23
Other countries	0,04	0,04	0,04	0,05
Total carrots	**6,78**	**6,92**	**6,95**	**8,06**

[108] During transportation with ferries, such as for example from Travemünde-Trelleborg, energy for the transport refrigeration euipment is obtaiend from the ferry's electricity generation system. No data were obtaiend about the amount of extra fuel needed for this purpose.

[109] *Mat och Transporter– en studie i energi användning.* 1994. Op cit. P. 19.

[110] Calculated using data on the consumed amounts in Table 1 and losses in Table 5.

[111] Places of consumption origin in section 4.

Table 20. Transported amounts of tomatoes. In kg per capita and year. [112]

Country of consumption origin	Place of consumption origin [113]	Leaving the wholesaler in Sweden	Leaving the importer in Sweden	Leaving the collector in the country of consumption origin	Leaving the producer at the place of consumption origin
Denmark		0,45	0,46	0,46	0,47
Netherlands		2,68	2,74	2,75	2,80
Spain	Murcia/ Almeria	1,04	1,06	1,07	1,17
	Las Palmas	1,04	1,06	1,07	1,17
Sweden		1,74	1,77	1,78	1,78
Other countries		0,26	0,27	0,27	0,29
Total tomatoes		**7,21**	**7,35**	**7,39**	**7,69**

The energy requirements for transporting the consumed amounts of carrots and tomatoes from the places of consumption origin to the place of consumption are shown in Table 21.

Table 21: Energy requirements for transporting the consumed amounts of carrots and tomatoes from the places of consumption origin to the place of consumption. In MJ per capita and year and MJ per kg. Including pre-combustion energy requirements. [114]

Country of consumption origin	Route	Transportation mode	MJ [115] Carrots per capita and year	Carrots per kg	Tomatoes per capita and year	Tomatoes per kg
Denmark		lorry	0,26	1,0	0,41	0,91
		ferry	0,0013	0,0048	0,0022	0,0048
Denmark total			0,26	1,0	0,41	0,92
Netherlands		lorry	0,42	1,5	4,1	1,5
		ferry	0,069	0,24	0,68	0,25
Netherlands total			0,49	1,8	4,8	1,8
Germany		lorry	0,038	1,3		

continued...

[112] Calculated using data on the consumed amounts in Table 1 and losses in Table 5.
[113] Places of consumption origin in section 4 unless included in this column.
[114] Transported amounts in Table 19-20, distances and modes of transport in Table 7-12 and section 8, energy requirements for different transportation modes in Table 17-18 and section 9. MJ per kg obtained by dividing MJ per capita by the consumed amounts in Table 1.
[115] Assuming energy requirements for road transport of 0,00113 MJ per kg-km when the distance exceeds 100 km, 0,00199 MJ per kg-km when distances range from 50 to 100 km and 0,00281 MJ per kg-km for road distances shorter than or equal to 50 km. Assuming energy requirements for sea transport of 0,0005 MJ per kg-km for ferries between Helsingör and Helsingborg and Travemünde and Trelleborg. Assuming energy requirements of 0,00015 MJ per kg-km for the sea transport between Las Palmas and Rotterdam and Ipswhich and Gothenburg.

Country of consumption origin	Route	Transportation mode	MJ Carrots per capita and year	Carrots per kg	Tomatoes per capita and year	Tomatoes per kg
		ferry	0,0029	0,10		
Germany total			0,041	1,4		
Great Britain		ship	0,0032	0,16		
		lorry	0,019	1,0		
Great Britain total			0,023	1,2		
Italy		lorry	0,45	3,1		
		ferry	0,014	0,096		
Italy total			0,46	3,2		
Spain [116]	Mainland by lorry	lorry			4,0	3,8
		ferry			0,10	0,10
	Mainland by lorry total				4,1	3,9
	The Canary Islands by ship	ship			0,53	0,52
		lorry			1,6	1,6
		ferry			0,16	0,16
	The Canary Islands by ship total				2,3	2,2
	The Canary Islands by plane	plane			1,0	49
		lorry			0,0079	0,38
	The Canary Islands by plane total				1,0	50
Spain total					7,4	3,5
Sweden		lorry	4,9	0,81	1,4	
Sweden total			4,9	0,81	1,4	0,78
"Other countries" [117] total			0,13	3,2	0,74	2,9
Total per capita/ average per kg			**6,3**	**0,92**	**15**	**2,0**

[116] Half the consumed amount (2,1 kg) from the mainland and half from the Canary Islands. Today (1996) only 2 % of the Spanish tomatoes from the Canary Islands are transported by plane and the remaining 98 % by ship to Rotterdam according to Bony Exportacion, op cit. A few years ago, however, about 40 % of the tomatoes from the Canary Islands were transported by plane according to the same source.

[117] Carrots: transported by a truck with energy requirements of 0,00113 MJ per kg-km.
Tomatoes: transported by a truck with energy requirements of 0,00199 MJ per kg-km.

The method for calculating average energy requirements for transporting the consumed amounts of carrots and tomatoes originating from Sweden (E_{ts}) in MJ per capita is, in brief :

$$E_{ts} = \sum_{i=a}^{e} l_{thi} * m_t * w_{tkm} * S_{hwi}$$

where

i= the different handling options a to e.

l_{thi}= the calculated road distance required for handling option $_i$ (km) (Table 16)

m_t= the transported amounts (kg) (Table 19 and Table 20)

W_{tkm}= energy requirements for transportation with lorries (MJ*kg-1*km-1) (Table 17 [118])

S_{hwi}= the assumed share of vegetables handled according to handling option $_i$. (Table 14)

11. Refrigeration during transportation †

Tomatoes and carrots are cold stored during transportation. Less than 1 % of the total volume of refrigerants may be emitted during the production process. [119]

11.a Lorries

Chlorofluorcarbons (CFCs) are commonly used as refrigerants in air-conditioning and transport refrigeration equipment in lorries. The most common refrigerant in lorries is CFC12 (CF_2Cl_2). [120]

Lorries with trailers may contain 10–13 kg CFC12 (3–5 kg in the front part where the maximum capacity is 7 tonnes and another 7–8 kg in the trailer where the maximum loading capacity is 18–23 tonnes) . In addition, approximately half of the existing lorries are equipped with air-conditioning where about 1,3 kg of CFC12 is used. Leakage's of CFC12 are on the order of 10–15 % yearly (transport refrigeration equipment) or 100 % yearly (air-conditioning equipment). [121] Consequently, Emissions from a lorry with a trailer may be in the order of 1,65–2,6 kg per year and from a lorry without a trailer 0,95–1,4 kg.

Lorries for long-range distribution may be used for 100-110 hours per week during the whole year (5 200– 5 700 hours per year). Lorries without trailers (used for regional and city distribution) may be used for 50–60 hours per week or 2 600–3 100 hours yearly. [122]

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[118] Energy requirements for distances exceeding 100 km are 0,00113 MJ per kg-km, for distances 50–100 km 0,00199 MJ per kg-km and for distances 0-50 km 0,00281 MJ per kg-km.

[119] *Integrated substance chain management*. 1991. Association of the Dutch Chemical Industry VNCI Leidschendam, the Netherlands, December. P. 1-20. Estimation for HCFC22.

[120] Frigoscandia, Frank Möller, personal communication, 0919. CFC 12 has been, and is still the most common freezing mixture. R 502 (a mixture of CFC115 and HCFC22) is used in less than 10 % of the existing fleet of lorries. This is confirmed by Hans-Olof Nilsson AB, Hans-Olof Nilsson, personal communication, 0496, who appreciates that CFC12 is used in 70 % of all lorries, R502 in 10 % and R134a (HFC134a) or R404a (a mixture of HFC 125, 134 a and 143 a) is used in the remaining 20 %.

[121] Frigoscandia, Frank Möller, op cit. and Hans-Olof Nilsson AB, Hans-Olof Nilsson, op cit.

[122] Sune Perssons Åkeri AB, Mats Arne, personal communication, 0596.

Emissions of CFC12 may therefore be $2{,}65*10^{-5}$ $g*kg^{-1}*hour^{-1}$ for lorries with trailers (load 15 000 kg) and $1{,}22*10^{-4}$ $g*kg^{-1}*hour^{-1}$ for lorries without trailers (load 3 500 kg).

11.b Ships

A common size for ships trafficking the route between the Canary Islands to Rotterdam is 420 000 cubic feet (or 14 600 m^3). The loading capacity is 2 710 tonnes. Such a ship may be used with used with load for 3600 hours per year. The most common refrigerant in transport refrigeration equipment in ships is HCFC22 (CF_2HCl). The amount of HCFC22 in the transport refrigeration equipment of a ship with the size mentioned above is 4 tonnes. About 20 % of the refrigerants may be leaked every year. [123] The duration of a trip from the Canary Islands to Rotterdam is 90 hours (Table 12)

Emissions of HCFC22 from transport refrigeration in ships may therefore be $8{,}20*10^{-5}$ $g*kg^{-1}*hour^{-1}$.

11.c Planes

Refrigerants in transport refrigeration equipment in aeroplanes are checked every 5–years and, there is almost never any need for re-filling. [124] Leakage's of refrigerants during transportation with planes have, based on this information, been estimated to 0 in this analysis.

12. Emissions of refrigerants during transportation of the consumed amounts of carrots and tomatoes †

Table 22 shows the emissions of refrigerants during transportation of the consumed amounts of carrots and tomatoes from the places of product origin to the place of consumption.

[123] Cool Carriers, Svante Hellberg, op cit.

[124] 767 Engineering, Copenhagen, Harding Larsen, personal communication, 0796.

Table 22: Emissions of refrigerants during transportation of the consumed amounts of carrots an tomatoes from the places of product origin to the place of consumption. In g per capita and year. Including pre-use emissions. [125]

Country of consumption origin	Route	Transportation mode	Emissions of refrigerants			
			Carrots		Tomatoes	
			CFC12	HCFC22	CFC12	HCFC22
Denmark		lorry	$1,2*10^{-04}$		$1,9*10^{-04}$	
Netherlands		lorry	$2,2*10^{-04}$		$2,1*10^{-03}$	
Germany		lorry	$2,1*10^{-05}$			
Great Britain		ship		$4,7*10^{-05}$		
		lorry	$9,8*10^{-06}$			
Italy		lorry	$1,9*10^{-04}$			
Spain [126]	Mainland by truck	lorry			$1,7*10^{-03}$	
	The Canary Islands by ship	ship				$7,7*10^{-03}$
		lorry			$8,3*10^{-04}$	
	The Canary Islands by plane	lorry			$3,8*10^{-06}$	
Spain total					$2,5*10^{-03}$	$7,7*10^{-03}$
Sweden [127]		lorry	$3,7*10^{-03}$		$1,1*10^{-03}$	
Other countries [128]		lorry	$4,2*10^{-05}$		$7,1*10^{-04}$	
Total per capita			**$4,3*10^{-03}$**	**$4,7*10^{-05}$**	**$6,6*10^{-03}$**	**$7,7*10^{-03}$**

13. Emissions factors for fuel †

Table 23 shows fuel-cycle CO_2 emissions for some fuels.

[125] Transported amounts in Table 19-20, transportation times in Table 7-12 and section 8 g-e. Emissions of refrigerants during transportation in section 11. Assuming emission rates for lorry transport of $2,65*10^{-5}$ g CFC12*kg^{-1}*hour^{-1} when distances exceed 100 km and emission rates of $1,22*10^{-4}$ g CFC12 *kg^{-1}*hour^{-1} when distances are shorter than 100 km.

[126] Half the consumed amount (2,1 kg) from the mainland and half from the Canary Islands. Today (1996) only 2 % of the Spanish tomatoes from the Canary Islands are transported by plane and the remaining 98 % by ship to Rotterdam. A few years ago, however, about 40 % of the tomatoes from the Canary Islands were transported by plane.

[127] Assuming emission rates for lorry transport of $7,41*10^{-5}$ g CFC12*kg^{-1}*hour^{-1}.

[128] Assumed to be transported by a truck with an emission rate of $2,65*10^{-5}$ g CFC12*kg^{-1}*hour^{-1}.

Table 23: Assumed CO_2 emissions from fossil-fuel cycles. In g CO_2 per MJ. [129]

Fuel	CO_2 fuel-cycle emissions, g per MJ
Gasoline	84
Diesel	81
Light fuel oil	81
Heavy fuel oil	80
Liquefied petroleum gas (LPG)	77
Light distillates, kerosene	84
Natural gas (NG)	68
Coal	110
Coke	133
Gasworks gas	100
Biomass [130]	15
District heating Sweden [131]	43
District heating Denmark [132]	110

14. Global Warming Potentials †

The Global Warming Potentials (GWPs) is an attempt to provide a measure of possible future commitment to global warming resulting from current anthropogenic emissions. "The index is defined as the cumulative radiative forcing between the present and some chosen later time "horizon" caused by a unit mass of gas emitted now, expressed relative to some reference gas (here CO_2 is used). The future global warming commitment of a greenhouse gas over the reference time horizon is the appropriate GWP multiplied by the amount of gas emitted. For example, GWPs could be used to calculate the effect of reducing CO_2 emissions by a certain amount compared with reducing CH4 emissions, for a specific time horizon". [133]

The GWPs for some greenhouse gases, referenced to the absolute GWP for CO_2, are shown in Table 24.

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[129] Gustavsson L., Börjesson P., Johansson B. and Svenningsson P. 1995. Reducing CO_2 emissions by substituting biomass for fossil fuels. In *Energy* Vol. 20. No. 11., 1097-1113. Adapted from Table 1, p. 1098. For all fuels except biomass and district heating.

[130] Börjesson P. 1996. Emissions of CO_2 from Biomass Production and Transportation in Agriculture and Forestry. In *Energy Convers. Mgmt.* Vol. 37, Nos 6-8, pp. 1235-1240. Figure 1. Calculated from about 4 kg C per GJ for biomass from rape seed and wheat in a fossil fuel-based energy system. Including transportation of 50 km by truck.

[131] Gustavsson L. and Johansson B. 1994. Cogeneration: One Way to Use Biomass Efficiently. In *Heat Recovery Systems & CHP* Vol. 14, No. 2, pp. 117-127. P. 124. Calculated from emissions of 1772 kton C from the Swedish district heating system in 1991 divided by a heat production of 41,7 Twh during the same year.

[132] Assumed to be produced by coal only with no conversion an distribution losses.

[133] *Climate Change 1994. Radiative Forcing of Climate Change and An Evaluation of the IPCC IS92 Emissions Scenarious.* 1995. Intergovernmental Panel on Climate Change, Cambridge University Press, 339 p. P. 32.

Table 24: Global Warming Potentials of some greenhouse gases, referenced to the absolute GWP for CO_2. The typical uncertainty is ± 35 % relative to the CO_2 reference. [134]

	GWP20	GWP100	GWP500
CO_2	1	1	1
CH_4	62	24,5	7,5
N_2O	290	320	180
CFC12	7900	8500	4200
HCFC22	4300	1700	520

15. Emissions in CO_2 equivalents during transportation of the consumed amounts of carrots and tomatoes ©

Table 25 and Table 26 show the emissions during transportation of the consumed amounts carrots and tomatoes from the places of consumption origin to the place of consumption in g CO_2 equivalents per capita and year and g CO_2 equivalents per kg.

[134] *Climate Change 1994. Radiative Forcing of Climate Change and An Evaluation of the IPCC IS92 Emissions Scenarious*. 1995. Op cit. P. 33 Table 5.

Table 25: Emissions in CO_2 equivalents during transportation of the consumed amounts of carrots from the places of consumption origin to the place of consumption In g per capita and year and g per kg. [135]

Country of consumption origin	Source of emissions	Emissions expressed in CO_2 equivalents			
		20-year perspective		100-year perspective	
		g CO_2 per capita and year	g CO_2 per kg	g CO_2 per capita and year	g CO_2 per kg
Denmark	fuel	21	81	21	81
	refrigerants	0,95	3,6	1,0	3,9
Denmark total		22	85	22	85
Netherlands	fuel	40	140	40	140
	refrigerants	1,7	6,2	1,8	6,6
Netherlands total		42	150	42	150
Germany	fuel	3,3	110	3,3	110
	refrigerants	0,17	5,7	0,18	6,1
Germany total		3,5	120	3,5	120
Great Britain	fuel	1,8	94	1,8	94
	refrigerants	0,28	9,6	0,16	5,6
Great Britain total		2,1	100	2,0	100
Italy	fuel	38	260	38	260
	refrigerants	1,5	10	1,6	11
Italy total		39	270	39	270
Sweden	fuel	400	66	400	66
	refrigerants	29	4,9	32	5,3
Sweden total		420	70	430	70
"Other countries"	fuel	10	260	10	260
	refrigerants	0,33	8,4	0,36	9,0
"Other countries" total		11	270	11	270
Total per capita/ average per kg		**540**	**80**	**550**	**80**

[135] Energy requirements for transporting carrots in Table 21, emissions of refrigerants in Table 22, emission factors for fuels in Table 23 and Global Warming Potentials in Table 24. Per kg emissions obtained by dividing the emissions per capita by the consumed amounts in Table 1.

Table 26: Emissions in CO_2 equivalents during transportation of the consumed amounts of tomatoes from the places of consumption origin to the place of consumption In g per capita and year and g per kg.[136]

Country of consumption origin	Source of emissions	Emissions expressed in CO_2 equivalents			
		20-year perspective		**100-year perspective**	
		g CO_2 per capita and year	g CO_2 per kg	g CO_2 per capita and year	g CO_2 per kg
Denmark	fuel	34	75	34	75
	refrigerants	1,5	3,4	1,7	3,7
Denmark total		35	78	35	78
Netherlands	fuel	390	150	390	150
	refrigerants	16	6,1	18	6,5
Netherlands total		410	150	410	150
Spain	fuel	600	290	600	290
	refrigerants	53	9,6	21	10
Spain total		660	300	620	300
Sweden	fuel	110	63	110	63
	refrigerants	8,5	4,9	9,1	5,3
Sweden total		120	68	120	68
"Other countries"	fuel	60	230	60	230
	refrigerants	5,6	9,6	6,1	10
"Other countries" total		66	240	66	240
Total per capita/average per kg		**1300**	**180**	**1200**	**170**

16. Use of electricity during storage †

The durability of carrots for direct consumption is 25 days while carrots harvested during the northern autumn (September and October) may be stored from up to May the next year. Table 1 showed that Danish carrots are imported throughout the year while carrots from other countries are mainly imported during the spring and early summer. Thus, most of the imported carrots are stored for only a short period, while the Danish and Swedish carrots are stored for months. The optimum storage temperature for carrots is 4° C and the energy requirements for storing carrots consists of cooling them from harvest temperature to the storage temperature and keeping them at that temperature during the whole storage.

Tomatoes are perishable products with an estimated durability of 14 days. The optimum storage temperature for tomatoes is 12°–14 ° C and the energy requirements for storing tomatoes consist of energy for cooling the tomatoes from about 25° C, which is the temperature in the greenhouse, to the storage temperature and then to keep the tomatoes at that temperature until they reach the retailer. The storage time for

[136] Energy requirements for transporting tomatoes in Table 21, emissions of refrigerants in Table 22, emission factors for fuels in Table 23 and Global Warming Potentials in Table 24. Per kg emissions obtained by dividing the emissions per capita by the consumed amounts in Table 1.

Swedish produced tomatoes was estimated to 47–52 hours.[137] This was the time elapsed from when the tomatoes left the producer until they reached the local retailers.

Information about the consumption of energy for storing vegetables was scarce. The best available information from the wholesalers was the yearly use of electricity (as specified on the electricity bill) and the amount of products handled per year. A possible way to estimate the energy needed per unit of product was then to divide the amount of energy used by the amount of products handled. Data from two large importers and retailers indicated that the energy consumption could be on the order of 126–133 MJ per ton. [138] Local wholesalers could not provide the same information because either the consumption of electricity or the amount of products handled was not known.

Estimations of this kind have some serious drawbacks. For example, the average use of electricity per unit of product in an establishment is not a fair way of estimating the average energy use for specific vegetables. For example, at ASK centralen in Helsingborg both Swedish and imported vegetables are handled. While the imported vegetables are received at 12° C, some of the Swedish produced vegetables must be cooled at the establishment with subsequent larger consumption of energy per unit of product than for the imported ones. Also, the storage time vary for different types of vegetables.

An expert of storage conducted a special study to estimate the needs for electricity for storing different vegetables. The estimations of energy requirements in this section are solely based on data from Alf Johansson AB [139] who made the estimations based on their extensive knowledge about of storage facilities, mainly within Sweden. The figures given are representative of the currently used technology used in Sweden today. Assuming old technology, or poor maintenance of the storage facilities, energy use could be 2-3 times larger. Best technology available could reduce the energy requirements presented here but slightly. The energy requirements for storing carrots and tomatoes are presented in Table 27.

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[137] Mattson K. and Ericsson N-A. 1988. *Studier av distributionsmiljöer från odlare till butiker i olika delar av Sverige*. Swedish University of Agricultural Sciences, Division of post-harvest fysiology and handling of horticultural produce, Alnarp, Sweden, 39 p. In Swedish.

[138] ASK-centralen AB, Hans Jönsson, personal communication, 0995. ICA Handlarna AB – Frukt och Grönt, Sigvard Olsson, personal communication, 0995.

[139] Alf Johansson AB is a consultancy firm which plans, constructs and maintains large scale cold-storage facilities for vegetables.

Table 27: Need of electricity for storing carrots and tomatoes. Final energy consumption in MJ electricity per kg. Excluding distribution losses.[140]

	MJ per kg stored product		
	time unit	Carrots	Tomatoes
Cooling	24 hours	0,0378 [141]	0,075
Short-term-storage	1 day	0,016	0,026
Long-term storage	October-November	0,096	
	October-December	0,127	
	October-January	0,158	
	October-February	0,188	
	October-March	0,225	
	October-April	0,267	
	October-May	0,312	

The final energy consumption including distribution losses is calculated by adding the distribution losses to the final energy consumption. The distribution losses in the countries of consumption origin are presented in Table 28.

Table 28: Distribution losses of electricity in the countries of consumption origin. [142]

Country	Distribution losses, %
Denmark	6,5
Netherlands	4,2
Germany	3,1
Great Britain	7,3
Italy	8,0
Spain	9,4
Sweden	7,0
"Other countries"	9,4 [143]

17. Electricity requirements for storing the consumed amounts of carrots and tomatoes †

The final electricity consumption including transmission losses for storing the consumed amounts of carrots and tomatoes are shown in Table 29 and Table 30. Table 29 and Table 30 also includes the assumptions about the storage time for carrots and tomatoes (excluding storage during transportation) and the storage locations.

[140] Alf Johansson AB, Alf Johansson, unpublished data, 0596.

[141] Air-cooling.

[142] *Energy balances of OECD countries 1991-1992* .1994 International Energy Agency, IEA Statistics, OECD Paris, 216 p. Figures calculated based on absolute figures on distribution losses and electricity supply..

[143] Assumed to be the same as in Spain.

Table 29: Final electricity consumption including transmission losses for storing the consumed amounts of carrots. According to countries of consumption origin. Including assumptions about the storage time (excluding storage during transportation) and the storage location. In MJ per capita and year and MJ per kg. [144]

Country of consumption origin	Time unit	Cooling/cold storage	Storage location	MJ per capita and year	MJ per kg
Denmark	24 hours	cooling	Denmark	0,015	0,055
	October-January	cold storage	Denmark	0,047	0,18
	2 days	cold storage	Sweden	0,0091	0,035
Denmark total	123 days			0,071	0,27
Netherlands	24 hours	cooling	Netherlands	0,015	0,054
	10 days	cold storage	Netherlands	0,051	0,18
	5 days	cold storage	Sweden	0,025	0,087
Netherlands total	16 days			0,090	0,32
Germany	24 hours	cooling	Germany	0,0016	0,053
	10 days	cold storage	Germany	0,0052	0,18
	5 days	cold storage	Sweden	0,0024	0,084
Germany total	16 days			0,0092	0,32
Great Britain	24 hours	cooling	Great Britain	0,0011	0,056
	10 days	cold storage	Great Britain	0,0036	0,18
	5 days	cold storage	Sweden	0,0017	0,087
Great Britain total	16 days			0,0064	0,33
Italy	24 hours	cooling	Italy	0,0082	0,056
	10 days	cold storage	Italy	0,027	0,19
	5 days	cold storage	Sweden	0,013	0,087
Italy total	16 days			0,048	0,33
Sweden	24 hours	cooling	Sweden	0,38	0,063
	October-January	cold storage	Sweden	1,2	0,20
Sweden total	121 days			1,6	0,27
"Other countries" total [145]	16 days			0,016	0,40
Total per capita /average per kg				**1,8**	**0,27**

[144] Transported (and stored) amounts in Table 19, time in storage in section 16, need of electricity for storage in Table 27 and distribution losses in Table 28. MJ per kg obtaiend by dividing electricity requirements per capita by the consumed amounts in Table 1.

[145] Electricity requirements per kg assumed to be the same as in Italy. Multiplied by the stored amount to obtain MJ per capita.

Table 30: Final electricity consumption including transmission losses for storing the consumed amounts of tomatoes According to countries of consumption origin. Including assumptions about the storage time (excluding storage during transportation) and the storage location. In MJ per capita and year and MJ per kg. [146]

Country of consumption origin	Time unit	Cooling/ cold storage	Storage location	MJ per capita and year	MJ per kg
Denmark	24 hours	cooling	Denmark	0,038	0,085
	1	cold storage	Denmark	0,013	0,029
	2	cold storage	Sweden	0,025	0,055
Denmark total	4			0,076	0,17
Netherlands	24 hours	cooling	Netherlands	0,22	0,082
	1	cold storage	Netherlands	0,076	0,028
	2	cold storage	Sweden	0,15	0,055
Netherlands total	4			0,45	0,17
Spain	24 hours	cooling	Spain	0,19	0,093
	1	cold storage	Spain	0,066	0,032
	2	cold storage	Sweden	0,12	0,055
Spain total	4			0,38	0,18
Sweden	24 hours	cooling	Sweden	0,15	0,085
	2	cold storage	Sweden	0,097	0,055
Sweden total	3			0,24	0,14
"Other countries" total [147]	4			0,053	0,20
Total per capita/average per kg				**1,2**	**0,17**

18. Refrigeration during storage †

Information about the use of, and the leakage's from refrigeration equipment for storing vegetables was scarce. Therefore, assumptions about the emissions rates from storage rooms may need to be revised in further analysis.

The most common refrigerant in storage rooms is HCFC22 (CF_2HCl). Storage facilities with open compressors may contain 1–2 kg of HCFC22 per installed kW. Such storage facilities are still commonly used and the average annual leakage from them are 30 %. Modern storage rooms may contain only 0,15 kg HCFC22 per installed kW. The annual leakage may be negligible. [148]

18. a Long-term storage for carrots

A typical storage room for carrots in long-term storage may have an installed power of 112 kW and a storage capacity of 1000 tonnes. [149]Consequently, the annual leakage from such a storage room may be 50,4 kg of HCFC22 if equipped with open compressors. If the whole capacity of such a storage room is used for 270 days per

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[146] Transported (and stored) amounts in Table 20, time in storage in section 16, need of electricity for storage in Table 26 and distribution losses in Table 27. MJ per kg obtaiend by dividing electricity requirements per capita by the consumed amounts in Table 1.

[147] Electricity requirements per kg assumed to be the same as in Spain. Multiplied by the stored amount to obtain MJ per capita.

[148] Alf Johansson AB, Alf johansson, op cit.

[149] Alf Johansson AB, Alf johansson, op cit.

year, the emissions of HCFC22 will be $1{,}89*10^{-4}$ $g*kg^{-1}*day^{-1}$ with production emissions of 1 % included.

18.b Short term-storage for carrots and tomatoes

A typical storage room for carrots in short-term storage and tomatoes may have an installed power of 8.6 kW and a storage capacity of 4 tonnes. [150] Consequently, the annual leakage from such a storage room may be 3,87 kg of HCFC22 if equipped with open compressors. If the whole storage capacity of such a storage room is used during the whole year, the emissions of HCFC22 will be $2{,}68*10^{-3}$ $g*kg^{-1}*day^{-1}$ with production emissions of 1 % included

19. Emissions of refrigerants during storage of the consumed amounts of carrots and tomatoes †

Table 31 shows the emissions of refrigerants during storage of the consumed amounts of carrots and tomatoes.

Table 31: Emissions of refrigerants during storage of the consumed amounts of carrots and tomatoes. According to countries of consumption origin. In g per capita and year. Including production emissions. [151]

Country of consumption origin	Emissions of refrigerants	
	Carrots	Tomatoes
	HCFC22	HCFC22
Denmark	$6{,}2*10^{-03}$	$4{,}9*10^{-03}$
Netherlands	$1{,}2*10^{-02}$	$2{,}9*10^{-02}$
Germany	$1{,}3*10^{-03}$	
Great Britain	$8{,}5*10^{-04}$	
Italy	$6{,}4*10^{-03}$	
Spain		$2{,}3*10^{-02}$
Sweden	$1{,}4*10^{-01}$	$1{,}4*10^{-02}$
"Other countries" [152]	$2{,}1*10^{-03}$	$3{,}7*10^{-03}$
Total per capita	0,17	0,11

20. Emission factors for electricity †

Emission factors for electricity were derived from data on the consumption of various fuels for electricity generation as well as estimations about the magnitude of greenhouse gas emissions from hydropower dams. Emissions of greenhouse gases

150 Alf Johansson AB, Alf johansson, op cit.

151 Transported amounts (and stored) amounts in Table 19-20, storage times in Table 29-30. Emission rates of refrigerants from storage rooms in section 18. Danish and Swedish carrots in long-term storage. Carrots from the Netherlands, Germany, Great Britain, Italy and "other countries" in short-term storage. All tomatoes in short term-storage.

152 Carrots: Emissions per kg assumed to be the same as in Germany. Multiplied by the stored amount to obtain the emissions per capita. Tomatoes: Emissions per kg assumed to be the same as in Spain. Multiplied by the stored amount to obtain the emissions per capita

from electricity production by nuclear power were not included in the analysis, nor emissions of N_2O and CH_4 from fuel combustion.

The fuels considered were coal, crude oil, petroleum products and gas. The amounts used for electricity generation of these fuels were multiplied by the CO_2 emission factors in Table 23. Pre-combustion energy requirements of 10 % were added to the figures on fuel consumption.

Biospheric carbon emissions from hydropower production were estimated to 2.5 grams of C per MJ electricity generated by hydropower production in Sweden if all the organic material is decomposed during the life-span of the dam (60 years) [153] However, these figures are probably overestimated as the rate of decomposition may be considerably lower. [154] If the former estimations are adhered to and 2 % [155] of the C is released as CH_4 and the rest as CO_2, the emissions of greenhouse gases may be on the order of 9,03 grams of CO_2 and $6{,}72 \cdot 10^{-5}$ grams of CH_4 per MJ electricity generated by hydropower in Sweden. These figures have been used throughout the analysis, and for all countries where the share of hydropower for electricity generation is 10 % or more of the total amount of electricity generated. Table 32 shows the relative shares of hydropower and coal as means for electricity generation in the countries of consumption origin. Table 32 also shows the calculated emissions of CO_2 and CH_4 from electricity generation in the countries of consumption origin.

Table 32: Electricity generation in the countries of consumption origin. Emissions of CO_2 and CH_4 in g per MJ generated in 1992. [156]

Country of consumption origin	Emissions, g per MJ generated 1992	
	CO_2	CH_4
Denmark	313	-
Netherlands	204	-
Germany	218	-
Great Britain	199	-
Italy	178	$1{,}27 \cdot 10^{-05}$
Spain	147	$1{,}06 \cdot 10^{-05}$
Sweden	19	$3{,}45 \cdot 10^{-05}$
"Other countries"	313 [157]	-

[153] Vattenfall Utveckling AB, Stockholm, Björn Svensson, personal communication., 0696. The average inundated area in Vattenfalls production plants is 24 km^2 per Twh. The dammed soil contains 13.5 kg C per m^2 (forest land) or 50 kg C per m^2 (peat land). and about 25 % of the dammed area is peat land and the rest forest land.

[154] Vattenfall Utveckling AB, Björn Svensson, op cit. Maybe only 20 % of the organic material is decomposed during the life-span of the dam.

[155] Assumption made by Vattenfall Utveckling AB, Björn Svensson, op cit..

[156] *Energy balances of OECD countries 1991–1992* .1994. Op cit. Emission factors for fuels in Table 23 and emissions factors for hydropower production in this section.

[157] Assumed to be the same as in Denmark.

21. Emissions in CO_2 equivalents during storage of the consumed amounts of carrots and tomatoes ©

Table 33 and Table 34 shows the emissions during storage of carrots and tomatoes in g CO_2 equivalents per capita and year g CO_2 equivalents per kg depending on the country of consumption origin.

Table 33: Emissions in CO_2 equivalents during storage of the consumed amounts of carrots In g per capita and year and g per kg according to countries of consumption origin. [158]

Country of consumption origin	Source of emissions	Emissions expressed in CO_2 equivalents			
		20-year perspective		100-year perspective	
		g CO_2 per capita and year	g CO_2 per kg	g CO_2 per capita and year	g CO_2 per kg
Denmark	electricity	19	74	19	74
	refrigerants	27	100	11	40
Denmark total		46	180	30	110
Netherlands	electricity	14	49	14	49
	refrigerants	53	190	21	74
Netherlands total		67	240	35	120
Germany	electricity	1,5	52	1,5	52
	refrigerants	5,5	190	2,2	74
Germany total		7,0	240	3,7	130
Great Britain	electricity	1,3	65	1,3	65
	refrigerants	3,7	190	1,5	74
Great Britain total		4,9	250	2,7	140
Italy	electricity	8,3	57	8,3	57
	refrigerants	27	190	11	74
Italy total		36	240	19	130
Sweden	electricity	31	4,6	31	4,6
	refrigerants	600	100	240	40
Sweden total		630	100	270	44
"Other countries"	electricity [159]	2,9	74	2,9	74
	refrigerants	9,1	230	3,6	90
"Other countries" total		12	300	6,5	160
Total per capita/average per kg		**800**	**120**	**370**	**54**

158 Transported amounts in Table 19, Global Warming Potentials in Table 24, final electricity consumption including transmission losses for storing carrots in Table 29, emissions of refrigerants during storage of carrots in Table 31 and emissions of CO_2 and CH_4 from electricity generation in Table 32. Per kg emissions obtained by dividing the emissions per capita by the consumed amounts in Table 1.

159 Assumed emissions of 73,5 g CO_2 and $1,2 * 10^{-6}$ g CH_4 per kg of product stored.

Table 34: Emissions in CO_2 equivalents during storage of the consumed amounts of tomatoes In g per capita and year and g per kg according to countries of consumption origin. [160]

Country of consumption origin	Source of emissions	Emissions expressed in CO_2 equivalents			
		20-year perspective		100-year perspective	
		g CO_2 per capita and year	g CO_2 per kg	g CO_2 per capita and year	g CO_2 per kg
Denmark	electricity	17	37	17	37
	refrigerants	21	47	8,3	19
Denmark total		38	84	25	55
Netherlands	electricity	63	24	63	24
	refrigerants	98	47	39	19
Netherlands total		160	71	100	42
Spain	electricity	41	20	41	20
	refrigerants	98	47	39	19
Spain total		138	67	79	38
Sweden	electricity	4,7	2,7	4,7	2,7
	refrigerants	61	35	24	14
Sweden total		66	38	29	17
"Other countries"	electricity [161]	5,1	20	5,1	20
	refrigerants	160	620	63	240
"Other countries total"		170	640	68	260
Total per capita/average per kg		570	79	300	42

22. Farm production †

22. a Use of fertilisers

Table 35 and 36 contains information about the recommended doses of N, P and K fertilisers for carrots and tomatoes in the countries of consumption origin.

[160] Transported amounts in Table 20, Global Warming Potentials in Table 24, final electricity consumption including transmission losses for storing tomatoes in Table 30, emissions of refrigerants during storage of tomatoes in Table 31 and emissions of CO_2 and CH_4 from electricity generation in Table 32. Per kg emissions obtained by dividing the emissions per capita by the consumed amounts in Table 1.

[161] Assumed emissions of 19,5 g CO_2 and 3,24 $* 10^{-6}$ g CH_4 per kg of product stored.

Table 35: The recommended doses of N, P and K fertilisers for carrots in the countries of consumption origin related to the harvest level. In g N, P and K per kg harvested carrot. All carrots cultivated on open ground.

Country of consumption origin	Recommended dose, g per kg carrot		
	N	P	K
Denmark [162]	2,5	1,17	4,17
Netherlands	1,6 [163]	0,85 [164]	2,2 [165]
Germany	2,5 [166]	0,44 [167]	4,98 [168]
Great Britain [169]	2,5	1,17	4,17
Italy [170]	2,5	1,17	4,17
Sweden	2,5 [171]	1,17 [172]	4,17 [173]
Other countries [174]	2,5	1,17	4,17

[162] The doses of N, P and K per kg carrot are assumed to be the same as in Sweden.

[163] Research station for arable farming an field production of vegetables, Lelystad, the Netherlands, Joop Alblas, faxed information, 1096. 100 kg N per ha. Assumed harvest of 6,2 kg per m^2.

[164] Research station for arable farming an field production of vegetables, op cit. 120 kg P_2O_5 per ha. Assumed harvest 6,2 kg per m^2.

[165] Research station for arable farming an field production of vegetables, op cit. 130-200 kg K_2O per ha for sandy soil. Assumed harvest 6,2 kg per m^2.

[166] Krug H.1991.*Gemüse production*.. Paul Parey Verlag Berlin and Hamburg. In German. P. 155. 0,25 kg N per dt.

[167] Krug H. 1991.,Op cit. 0,10 kg P_2O_5 per dt carrots.

[168] Krug H.1991. Op cit. 0,60 kg K_2O per dt carrots.

[169] The doses of N, P and K per kg carrot are assumed to be the same as in Sweden.

[170] The doses of N, P and K per kg carrot are assumed to be the same as in Sweden.

[171] *Bidragskalkyler för köksväxter på friland*. 1991. County Administration Board in Östergötland, The Department of Agriculture, Linköping, Sweden, 125 p. In Swedish. P. 33, carrots of medium size. 75 kg N for a harvest of 300 dt.

[172] *Bidragskalkyler för köksväxter på friland*. 1991.Op cit. P. 33, carrots of medium size. 35 kg of P for a harvest of 300 dt.

[173] *Bidragskalkyler för köksväxter på friland*. 1991.Op cit. P. 33, carrots of medium size. 125 kg of K for a harvest of 300 dt.

[174] The doses of N, P and K per kg carrot are assumed to be the same as in Sweden.

Table 36: The recommended doses of N, P and K fertilisers for tomatoes in the countries of consumption origin related to the harvest level. In g N, P and K per kg harvested tomato.

Country of consumption origin	Cultivation on open ground/ cultivation under glass	Recommended dose, g per kg tomato		
		N	P	K
Denmark [175]	under glass	5	0,9	6,5
Netherlands	under glass	2,3 [176]	0,5 [177]	3,3 [178]
Spain	open ground	19 [179]	7,7 [180]	21 [181]
Sweden	under glass	5 [182]	0,9 [183]	6,5 [184]
Other countries [185]	open ground	19	7,7	21

22. b Use of fuel, electricity and lubricating oils for machines and implements

Carrots

According to Swedish estimations, tractor power is needed during 32 hours for producing 300 dt of carrots. The tractor is assumed to require 11 litres of diesel and 0,3 litres of lubricating oil per hour of operation. For irrigation, 2160 MJ of electricity are needed for obtaining a harvest of 300 dt of carrots. [186]

One litre of diesel or light fuel oil has an energy content of 42,5 MJ with pre-combustion energy supplements included [187] Therefore 0, 5 MJ of diesel and 0,01 MJ of lubricating oils are needed per kg carrot harvested. The final electricity consumption for irrigation excluding distribution losses is 0,072 MJ per kg carrot harvested.

The figures mentioned above have been used for estimating greenhouse gas emissions from farm production of carrots in all countries of consumption origin.

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[175] Assumed to be the same as in Sweden.

[176] *Miljomaessiga konsekvenser ved produktion af danske och udenlandske gronsaker og frugt.* 1995. Econet, Copenhagen, 34 pages. In Danish. P.17. 0,1149 kg N per m^2. Assumed harvest of 50 kg per m^2.

[177] *Miljomaessiga konsekvenser ved produktion af danske och udenlandske gronsaker og frugt.* 1995. Op cit. 0,0254 kg P per m^2. Assumed harvest of 50 kg per m^2.

[178] *Miljomaessiga konsekvenser ved produktion af danske och udenlandske gronsaker og frugt.* 1995. Op cit. 0,1635 kg K per m^2. Assumed harvest of 50 kg per m^2.

[179] *Miljomaessiga konsekvenser ved produktion af danske och udenlandske gronsaker og frugt.* 1995. Op cit. 0,2462 kg N per m^2. Assumed harvest level of 13 kg per m^2.

[180] *Miljomaessiga konsekvenser ved produktion af danske och udenlandske gronsaker og frugt.* 1995. Op cit. 0,0996 kg P per m^2. Assumed harvest level of 13 kg per m^2.

[181] *Miljomaessiga konsekvenser ved produktion af danske och udenlandske gronsaker og frugt.* 1995. Op cit. 0,2744 kg K per m^2. Assumed harvest level of 13 kg per m^2.

[182] Trädgårdsutveckling AB, Alnarp, Sweden, Torbjörn Hansson, personal communication, 0496. 200 kg N per 1000 m^2. Assumed harvest level of 40 kg per m^2.

[183] Trädgårdsutveckling AB, Torbjörn Hansson, op ci.t. The P-requirements are 18 % of the N-requirements.

[184] Trädgårdsutveckling AB, Torbjörn Hansson, op cit. The K-requirements are 130 % of the N-requirements.

[185] Assumed to be the same as in Spain.

[186] *Bidragskalkyler för köksväxter på friland.* 1991. Op cit. P. 33.

[187] Stout B.A.(Editor-in-Chief). 1992. Op cit.

Tomatoes

Little, or no, fuel such as diesel is used for machines and implements in greenhouses. Therefore, I have not included any figures on the consumption of fuel and lubricating oils for tomatoes produced in Denmark, the Netherlands and Sweden. Some electricity is used for lighting and implements in greenhouses but those requirements have not been estimated in this analysis.

Spanish tomatoes are grown on the open ground, although, according to information, under plastic roofs. No information concerning the use of energy for farm production in Spain was found.

A study of tomato production on the open ground in northern Italy estimated the use of diesel during farm production to 7,3 kg per tonne harvested tomatoes. The use of lubricating oils was estimated to 0,13 kg per tonne harvested tomato. [188] These figures include the use of fuel for irrigation. The average specific gravity for diesel is 0,87 (1 litre of diesel weighs 0,87 kg) and the same figure for lubricating oils is 0,9. With energy contents of diesel and lubricating oils as stated above, the use of diesel and lubricating oils are 0,36 MJ and 0,0061 MJ per kg tomato respectively including pre-combustion energy requirements.

22. c Use of fuel for heating

Greenhouses in Denmark, the Netherlands and Sweden are heated. Estimates of the energy requirements for heating vary between different sources:

The average energy requirements (excluding pre-combustion energy requirements) for heating Swedish greenhouses were reported to 1627 MJ per m^2 in 1993. [189] Plausible energy requirements for heating greenhouses where the dominant crop is tomatoes were estimated to 2016 MJ per m^2 and year. The expected yield in such greenhouses is 40 kg tomatoes per m^2 and year. [190] The energy requirements per kg tomato, including pre-combustion energy requirements, are calculated to 55,4 MJ in the latter case.

The energy requirements for heating a greenhouse with tomatoes in Denmark were reported to 2932 MJ per m^2 and year (excluding pre-combustion energy requirements). The harvest in this case was 42-45 kg tomato per m^2 and year. [191] The energy requirements per kg tomato including pre-combustion energy requirements are calculated to 74 MJ for the Danish case.

The energy requirements for Dutch vegetable production under glass were reported to 1 540 MJ per m^2 in 1993. [192] Information from Dutch tomato growers are that 2400 MJ per m^2 and year are used in greenhouses with a yield of 50 kg tomatoes per m^2 and year. [193] The latter figures suggest that the energy requirements per kg tomato including pre-combustion energy requirements are 52,8 MJ for Dutch conditions.

Since there is a difference in climate between the Netherlands, Denmark and Sweden, one would expect lower energy requirements per kg tomato in the Netherlands than in Denmark or Sweden.

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188 The Swedish Institute for Food Research (SIK) Gothenburg, Sweden, Karin Andersson, personal communication, 0996. Karin Andersson based her estimations on a study carried out at a medium sized farm in Northern Italy supplying about 1000 tonnes of tomatoes per year.

189 *Trädgårdsodlingen i Sverige 1984-1993- en statistiksammanställning.* 1995. Op cit. P. 10.

190 Trädgårdsutvecking AB, Gunnel Larsson, personal communication, 1096

191 *Miljomaessiga konsekvenser ved produktion af danske och udenlandske gronsaker og frugt.* 1995. Op cit. P. 17.

192 *Bedrijfsuitkomsten in de tuinbouw (BUT). Boekjaar 1994 en vergelijkingen met voorgaande jaren.* 1996. Landbouw-Econimisch Instituut, Afdelning Tuinbouw, Den Haag, Periodieke Rapportage 38-94, pp. 155. In Dutch. P. 50.

193 *Miljomaessiga konsekvenser ved produktion af danske och udenlandske gronsaker og frugt.* 1995. Op cit. P.17.

In this analysis, energy requirements for heating greenhouses were chosen to be 55,4 MJ per kg tomato for production in Denmark and Sweden and 52,8 MJ per kg tomato for production in the Netherlands

Table 37 shows the energy requirements for heating greenhouses where the dominant crops is tomatoes in Denmark, Sweden and the Netherlands as well as the energy carriers used for heating greenhouses in general in those countries.

Table 37: Energy requirements for heating greenhouses where the dominant crop is tomatoes. In MJ per kg tomato. Share of energy carriers for heating greenhouses. According to countries of consumption origin.

Country of consumption origin	Energy requirements	Energy carriers, share							
	MJ per kg tomato	Oil	Diesel	Biomass	Coal and coke	District heating	Electricity	Natural gas	Total
Denmark [194]	55,4	0,28	0,09	0,01	0,25	0,19	-	0,18	1
Netherlands [195]	52,8							0,99	0,99
Sweden [196]	55,4	0,6		0,03	0,07	0,06	0,11	0,13	1

23. Energy requirements during farm production of the consumed amounts of carrots and tomatoes †

The energy requirements during farm production of the consumed amounts of carrots and tomatoes are shown in Table 38.

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[194] *Agricultural Statistics1993*. 1994. Statistics Denmark, Copenhagen, 302 p. In Danish. Contents and Tables in English. P.113. Energy consumption in greenhouse farms by type of energy. Fuel oil, coal, coke, and biomass in tonnes. Diesel, natural gas and district heating in m^3. Specific gravity of fuel oil 0,91, energy content 42,5 MJ per l. Energy content of diesel 42,5 MJ per l. Energy content of natural gas 42,9 MJ per m^3. Energy content of coal 33,3 MJ per kg. Energy content of district heating 150 MJ per m^3. Energy content of wood 19,4 MJ per kg. All figures includin pre-combustion energy requirements.

[195] Landbouw-Econimisch Instituut, Jo Wijnands, personal communication, 0596. For the share of gas as an energy carrier when heating greenhouses in the Netherlands.

[196] *Trädgårdsodlingen i Sverige 1984-1993- en statistiksammanställning*. 1995. Op cit. Op cit. P. 10.

Table 38: Energy requirements during farm production of the consumed amounts of carrots and tomatoes. According to countries of consumption origin. In MJ per capita and year and MJ per kg product. Including pre-combustion energy requirements. [197]

Country of consumption origin	Source of energy use	MJ			
		Carrots		Tomatoes	
		per capita and year	per kg	per capita and year	per kg
Denmark	Fuels for heating	-		26	59
	Diesel	0,17	0,64	negligible	negligible
	Lubricating oils	0,0046	0,017	negligible	negligible
	Electricity	0,03	0,098		
Denmark total		0,26	0.76	26	59
Netherlands	Fuels for heating	-		150	56
	Diesel	0,16	0,55	negligible	negligible
	Lubricating oils	0,0043	0,02	negligible	negligible
	Electricity	0,024	0,083		
Netherlands total		0,18	0,65	150	56
Germany	Fuels for heating	-			
	Diesel	0,016	0,55		
	Lubricating oils	0,00044	0,02		
	Electricity	0,0024	0,083		
Germany total		0,019	0,65		
Great Britain	Fuels for heating	-			
	Diesel	0,011	0,56		
	Lubricating oils	0,00030	0,015		
	Electricity	0,0024	0,086		
Great Britain total		0,013	0,66		
Italy	Fuels for heating	-			
	Diesel	0,081	0,55		
	Lubricating oils	0,0022	0,015		
	Electricity	0,013	0,086		
Italy total		0.096	0.66		

continued...

197 Transported (and produced) amounts in Table 19-20, use of fuel, lubricating oils and electricity in section 22b-22c, Distribution losses of electricity in Table 28. MJ per kg obtaiend by dividing electricity requirements per capita by the consumed amounts in Table 1.

Country of consumption origin	Source of energy use	MJ			
		Carrots		Tomatoes	
		per capita and year	per kg	per capita and year	per kg
Spain	Fuels for heating			-	
	Diesel			0,84	0,40
	Lubricating oils			0,014	0,0069
	Electricity			-	
Spain total				0,85	0,41
Sweden	Fuels for heating	-		100	58
	Diesel	3,61	0,60	negligible	negligible
	Lubricating oils	0,10	0,016	negligible	negligible
	Electricity	0,56	0,093		
Sweden total		4,26	0,71	100	58
Other countries [198] total		0,041	1,0	0,12	0,47
Total per capita/average per kg		**4,8**	**0,71**	**280**	**39**

24. N_2O emissions from farm land †

Losses of N-fertilisers in the form of N_2O vary because of differences in soil properties, type of fertiliser and management practices. "Optimal environments for N_2O production are warm, moist soils with little oxygen, neutral-pH, and readily available organic carbon, nitrogen, and other nutrients". [199] L. Skärby et al reports emission rates of 0-3 % for Swedish conditions, and emissions rates of 0,07-2,7 % for Danish conditions [200] Nevison et al. reports emission rates of 0-20 % of the N-fertiliser applied with the highest rates in the tropics associated with broadcast fertilisation. [201] Robertsson used an estimated annual loss rate of 1% in her estimation of annual antropogenic emissions of N_2O from, among others, farm land. [202] Nevison et al, [203] suggest that the "consideration of both the short and long-term fates of fertiliser nitrogen indicates that the N_2O/fertiliser-N yield may be 2 % or more".

Most tomatoes produced in greenhouses are grown in substrates such as rock-wool. There are no reported estimations of N_2O emissions from such substrates. In

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[198] Carrots: MJ per kg as in Sweden. .Tomatoes: MJ per kg as in Spain. Multiplied by the produced amounts to obtain MJ per capita.

[199] Nevison C.D., Esser G., Holland E.A. 1996. A Global Model of Changing N_2O Emissions from Natural and Perturbed Soils. In *Climatic Change* 32: 327-378. P. 331.

[200] Skärby L., Ferm M., Johansson M. , Klemedtsson L., Lövblad G. , Pihl Karlsson G. and Zetterberg L. 1995. *Airborne Pollutants and green-house gases: The role of agriculture as source and recipient.* Swedish Environmental Research Institute (IVL), Stockholm, Sweden, IVL-publ. B1181, 23 p. P. 12-13 Appendix 2.

[201] Nevison C.D. , Esser G., Holland E.A. 1996. Op cit.

[202] Robertsson K. 1991. Emissions of N_2O in Sweden-Natural and Antrophogenic Sources. *Ambio* Vol 20 NO. 3-4, pp. 151-154. P. 152.

[203] Nevison C.D., Esser G., Holland E.A. 1996. Op cit. P. 327..

this analysis, 2 % of the amount of N-fertiliser applied is supposed to leave the farmland as N_2O.

25. N_2O emissions from farm land during farm production of the consumed amounts of carrots and tomatoes †

The N_2O emissions during farm production of the consumed amounts of carrots and tomatoes are shown in Table 39.

Table 39: N_2O emissions from farm land during farm production of the consumed amounts of carrots and tomatoes. According to countries of consumption origin. In g N_2O per capita and year and g N_2O per kg product. [204]

Country of consumption origin	N_2O, g			
	Carrots		Tomatoes	
	per capita and year	per kg	per capita and year	per kg
Denmark	0,026	0,10	0,075	0,17
Netherlands	0,016	0,056	0,20	0,076
Germany	0,0026	0,087		
Great Britain	0,0017	0,087		
Italy	0,013	0,087		
Spain			1,4	0,67
Sweden	0,57	0,095	0,29	0,16
"Other countries" [205] total	0,0055	0,095	0,20	0,77
Total per capita/average per kg	**0,63**	**0,093**	**2,2**	**0,30**

26. Emissions from heating of greenhouses †

Table 40 shows the calculated emissions of CO_2 from heating of greenhouses where the dominant crop is tomatoes in the different countries of consumption origin.

[204] Amounts of N-fertilizers applied in Table 35-36. N_2O emissions in section 24. The share of N expected to form N_2O (2 % of the N-fertlizer applied) was multiplied by 1,57 to obtain the N_2O emissions. N_2O emissions per kg obtaiend by dividing N_2O emissions per capita by the consumed amounts in Table 1.

[205] Carrots: Emissions per kg as in Sweden. Tomatoes: emissions per kg as in Spain. Multiplied by the produced amounts in Table 19-20.

Table 40: Emissions of CO_2 from heating greenhouses where the dominant crop is tomatoes. According to the countries of consumption origin. In g CO_2 per kg tomato and g CO_2 per MJ. Pre-combustion emissions included. [206]

Country of consumption origin	g CO_2 per kg tomato	g CO_2 per MJ
Denmark	5030	91
Netherlands	3560	68
Sweden	3790	69

27. Emissions in CO_2 equivalents during farm production of the consumed amounts of carrots and tomatoes ©

Table 41 and Table 42 shows the emissions during farm production of the consumed amounts carrots and tomatoes in g CO_2 equivalents per capita and year and in g CO_2 equivalents per kg according to the countries of consumption origin

Table 41: Emissions in CO_2 equivalents during farm production of the consumed amounts of carrots. According to countries of consumption origin. In g per capita and year and in g per kg. [207]

Country of consumption origin	Source of emissions	Emissions expressed in CO_2 equivalents			
		20-year perspective		100-year perspective	
		g CO_2 per capita and year	g CO_2 per kg	g CO_2 per capita and year	g CO_2 per kg
Denmark	All fuels for heating	-	-	-	-
	Diesel	14	52	14	52
	Lubricating oils	0,37	1,4	0,37	1,4
	N-fertiliser	7,7	29	8,5	32
	Electricity	8,1	31	8,1	31
Denmark total		30	110	31	120
Netherlands	All fuels for heating	-	-	-	-
	Diesel	13	45	13	45
	Lubricating oils	0,34	1,2	0,34	1,2
	N-fertiliser	4,6	16	5,1	18
	Electricity	4,8	17	4,8	17
Netherlands total		23	80	23	81
Germany	All fuels for heating	-	-	-	-
	Diesel	1,3	45	1,3	45
	Lubricating oils	0,036	1,2	0,036	1,2
continued...	N-fertiliser	0,74	25	0,82	28

206 Energy consumption per kg tomato in Table 37. Share of fuels for heating greenhouses in Table 37. Emission factors for fuels in Table 23.

207 Energy requirements during farm production of carrots in Table 38, emission factors for fuels in Table 23, Global Warming Potentials in Table 24, emissions factors for electricity in Table 32, N_2O/fertilizer N-yield during farm production in Table 39. Emissions per kg obtaiend by dividing the emissions per capita with the consumed amounts in Table 1.

Country of consumption origin	Source of emissions	Emissions expressed in CO_2 equivalents			
		20-year perspective		100-year perspective	
		g CO_2 per capita and year	g CO_2 per kg	g CO_2 per capita and year	g CO_2 per kg
	Electricity	0,53	18	0,53	18
Germany total		2,6	90	2,7	92
Great Britain	All fuels for heating	-	-	-	-
	Diesel	0,88	45	0,88	45
	Lubricating oils	0,024	1,2	0,024	1,2
	N-fertiliser	0,49	25	0,55	28
	Electricity	0,33	17	0,33	17
Great Britain total		1,7	89	1,8	91
Italy	All fuels for heating	-	-	-	-
	Diesel	6,6	45	6,6	45
	Lubricating oils	0,18	1,2	0,18	1,2
	N-fertiliser	3,7	25	4,1	28
	Electricity	2,2	15	2,2	15
Italy total		13	87	13	89
Sweden	All fuels for heating	-	-	-	-
	Diesel	290	49	290	49
	Lubricating oils	7,9	1,3	7,9	1,3
	N-fertiliser	170	27	180	30
	Electricity	11	1,8	11	1,8
Sweden total		480	79	490	82
"Other countries" total [208]		6,5	150	6,7	150
Total per capita/average per kg		**550**	**82**	**570**	**84**

208 Emissions of CO_2 per kg from diesel,lubricating oils and electricity as in Denmark. Multiplied by the produced amounts amounts in Table 19.

Table 42: Emissions in CO_2 equivalents during farm production of the consumed amounts of tomatoes. According to countries of consumption origin. In g per capita and year and g per kg. [209]

Country of consumption origin	Source of emissions	Emissions expressed in CO_2 equivalents			
		20-year perspective		100-year perspective	
		g CO_2 per capita and year	g CO_2 per kg	g CO_2 per capita and year	g CO_2 per kg
Denmark	All fuels for heating	2400	5000	2400	5000
	Diesel	-	-	-	-
	Lubricating oils	-	-	-	-
	N-fertiliser	22	48	24	53
	Electricity	-	-	-	-
Denmark total		2400	5100	2400	5100
Netherlands	All fuels for heating	10000	3600	10000	3600
	Diesel	-	-	-	-
	Lubricating oils				
	N-fertiliser	59	22	65	24
	Electricity	-	-	-	-
Netherlands total		10000	3600	10000	3600
Spain	All fuels for heating	-	-	-	-
	Diesel	68	33	68	33
	Lubricating oils	1,2	0,56	1,2	0,56
	N-fertiliser	400	200	450	220
	Electricity				
Spain total		470	230	520	250
Sweden	All fuels for heating	6900	3800	6900	3800
	Diesel	-	-	-	-
	Lubricating oils	-	-	-	-
	N-fertiliser	83	48	91	53
	Electricity	-	-	-	-
Sweden total		7000	3800	7000	3800
"Other countries" total [210]		68	262	74	290
Total per capita/average per year		**20000**	**2800**	**20000**	**2800**

[209] Energy requirements during farm production of tomatoes in Table 38, emission factors for fuels in Table 23, Global Warming Potentials in Table 24, emissions factors for electricity in Table 32, N2O/fertiliser N-yield during farm production in Table 39. Emissions per kg obtaiend by dividing the emissions per capita with the consumed amounts in Table 1.

[210] Emissions of CO_2 per kg from diesel and lubricating oils as in Spain. Multiplied by the produced amount from Table 20.

28. Energy requirements for production and transportation of fertilisers †

Data on the energy requirements for producing and transporting fertilisers were reviewed by P. Börjesson, [211] who found that estimations of such requirements had decreased in literature dating from 1978 to 1992. The same author used energy requirements of 0,036 MJ per g N, 0,0072 MJ per g P and 0,00432 MJ per g K for his energy analysis of different crops for biomass production. The same energy requirements for production and transportation of fertilisers will be used in this analysis.

The assumed distribution of energy carriers used in the production of fertilisers for food production is given in Table 43.

Table 43: Average energy carriers embodied in fertilisers for food production. [212]

Input	Liquid fossil fuel, %	Natural gas, %	Electricity, %
Nitrogen fertiliser	5	90	5
Phosphorous and potash fertilisers	30	25	45

29. Emissions from production and transportation of fertilisers †

Table 44 shows the calculated emissions of CO_2 from the production and transportation of fertilisers.

Table 44: Emissions of CO_2 from the production and transportation of fertilisers. In g CO_2 per g N, P or K. Pre-combustion emissions included. [213]

Type of fertiliser	g CO_2 per g N, P or K
Nitrogen fertiliser	3,3
Phosphorous fertiliser	1,1
Potash fertiliser	0,64

[211] Börjesson P. 1994. *Energy Analysis of biomass production in Swedish agriculture and forestry-today and around 2015*. Department of Environmental and Energy Systems Studies, Lund University, Institute of Technology, IMES/EESS Report No 17, 63 p. In Swedish. Abstract in English. P. 26.
[212] P. Börjesson. 1996. Op cit. Börjesson used these estimations for an energy analysis of biomass production.
[213] Energy consumption for producing and transporting fertilisers in section 28. Energy carriers embodied in fertiliser inputs in Table 43. The electricity is assumed to be produced from equal proportions of coal and oil, with a conversion efficiency of 40 %. Emission factors for fuel in Table 23.

In addition to the energy related emissions of CO_2 estimated in Table 44, process emissions of N_2O are reported during the production of N-fertilisers. Such emissions were estimated to 0,016 g N_2O per g N. [214]

30. Energy requirements for producing the fertilisers needed for the consumed amounts of carrots and tomatoes. ©

Table 45 shows the energy requirements for the production and transportation of the fertilisers needed for producing the consumed amounts of carrots and tomatoes.

Table 45: Energy requirements for production and transportation of the fertilisers needed for the consumed amounts of carrots and tomatoes. According to countries of consumption origin. In MJ per capita and year and MJ per kg product. Including pre-combustion energy requirements. [215]

Country of consumption origin	Type of fertiliser	MJ			
		Carrots		Tomatoes	
		per capita and year	per kg	per capita and year	per kg
Denmark	N	0,036	0,14	0,10	0,23
	P	0,0028	0,011	0,0031	0,0069
	K	0,0061	0,023	0,013	0,030
Denmark total		0,045	0,17	0,12	0,27
Netherlands	N	0,022	0,078	0,28	0,11
	P	0,0019	0,007	0,010	0,0038
	K	0,0030	0,011	0,040	0,015
Netherlands total		0,027	0,095	0,33	0,12
Germany	N	0,0035	0,12		
	P	0,0001	0,0035		
	K	0,0007	0,024		
Germany total		0,0043	0,15		
Great Britain	N	0,0023	0,12		
	P	0,0002	0,0093		
	K	0,0004	0,020		
Great Britain total		0,0029	0,15		
Italy	N	0,018	0,12		
continued...	P	0,0014	0,0093		

[214] B.P. Weidema, R. L. Pedersen, T. S. Drivsholm. 1995. *Life Cycle Screening of Food Products-Two Examples and Some Methodological Proposals*. Danish Academy of Technical Sciences, Report from the ATV project "Life Cycle Assessment on Food- Development of a Method to Apply the Life Cycle Concept on Products within the Food Sector", Lyngby, Denmark, 193 p. P. 51.

[215] Transported (and produced) amounts in Table 19-20, recommended doses of fertilisers in Table 35-36, energy requirements for production and transportation of fertilisers in section 28. MJ per kg obtained by dividing the energy requirements per capita by the consumed amounts in Table 1.

Country of consumption origin	Type of fertiliser	MJ			
		Carrots		Tomatoes	
		per capita and year	per kg	per capita and year	per kg
	K	0,0029	0,020		
Italy total		0,022	0,15		
Spain	N			1,9	0,92
	P			0,13	0,062
	K			0,21	0,10
Spain total				2,3	1,1
Sweden	N	0,78	0,13	0,39	0,23
	P	0,061	0,010	0,012	0,0068
	K	0,13	0,022	0,051	0,029
Sweden total		0,97	0,16	0,46	0,26
"Other countries" [216] **total**		0,0094	0,24	0,33	1,3
Total per capita/average per kg		**1,1**	**0,16**	**3,5**	**0,48**

31. Emissions of N_2O during production of the N-fertilisers needed for the consumed amounts of carrots and tomatoes. †

Emissions of N_2O during the production of the N-fertilisers needed for the consumed amounts of carrots and tomatoes are shown in Table 46.

[216] Carrots: MJ per kg as in Sweden. .Tomatoes: MJ per kg as in Spain. Muliplied by the produced amounts in Table 19-20.

Table 46: Emissions of N_2O during the production of N-fertilisers needed for the consumed amounts of carrots and tomatoes. According to countries of consumption origin. In g per capita and year and g per kg. [217]

Country of consumption origin	**N_2O, g**			
	Carrots		**Tomatoes**	
	per capita and year	**per kg**	**per capita and year**	**per kg**
Denmark	0,013	0,051	0,038	0,085
Netherlands	0,0081	0,029	0,10	0,039
Germany	0,0013	0,044		
Great Britain	0,0009	0,044		
Italy	0,0065	0,046		
Spain			0,71	0,34
Sweden	0,29	0,048	0,15	0,084
"Other countries" [218] total	0,0023	0,058	0,10	0,39
Total per capita/average per kg	**0,32**	**0,047**	**1,1**	0,15

32. Emissions in CO_2 equivalents for producing the fertilisers needed for the consumed amounts of carrots and tomatoes. ©

Table 47 and Table 48 shows the emissions in CO_2 equivalents during production and transportation of the fertilisers needed for the consumed amounts carrots and tomatoes in g CO_2 equivalents per capita and year and g CO_2 equivalents per kg according to the countries of consumption origin

[217] Recommended doses of N-fertilisers in Table 35-36. emissions of N_2O per g N produced in section 29, transported (and produced) amounts in Table 19-20. N_2O emissions per kg obtained by dividing N_2O emissions per capita by the consumed amounts in Table 1.

[218] Carrots: Emissions per kg as in Sweden. Tomatoes: emissions per kg as in Spain. Multiplied by the produced amounts in Table 19-20.

Table 47: Emissions in CO_2 equivalents during production and transportation of the fertilisers needed for the consumed amounts of carrots. According to countries of consumption origin. In g per capita and year and g per kg. [219]

Country of consumption origin	Type of fertiliser	Emissions expressed in CO_2 equivalents			
		20-year perspective		100-year perspective	
		g CO_2 per capita and year	g CO_2 per kg	g CO_2 per capita and year	g CO_2 per kg
Denmark	N	6,7	26	7.2	27
	P	0,42	1,6	0,42	1,6
	K	0,90	3,4	0,90	3,4
Denmark total		8,1	31	8,5	32
Netherlands	N	4,0	14	4,3	15
	P	0,29	1,01	0,29	1,0
	K	0,45	1,58	0,45	1,6
Netherlands total		4,8	17	5,0	18
Germany	N	0,65	22	0,69	23
	P	0,02	0,52	0,02	0,52
	K	0,10	3,6	0,10	3,6
Germany total		0,77	26	0,81	28
Great Britain	N	0,43	23	0,45	24
	P	0,03	1,4	0,03	1,4
	K	0,06	3,0	0,06	3,0
Great Britain total		0,52	27	0,54	28
Italy	N	3,2	22	3,4	24
	P	0,20	1,4	0,20	1,4
	K	0,44	3,0	0,44	3,0
Italy total		3,9	27	4,1	28
Sweden	N	144	24	153	25
	P	9,1	1,51	9,1	1,5
	K	12	1,94	12	1,9
Sweden total		165	28	174	29
"Other countries"	N	1,2	29	1,3	32
	P	0,07	1,8	0,07	1,8
	K	0,2	3,9	0,16	3,9
"Other countries" total		1,4	35	1,5	37
Total per capita/average per kg		**180**	**27**	**190**	**29**

219 Recommended doses of fertilisers in Table 35, emissions of CO_2 from fertiliser production in Table 44, transported (and produced) amounts in Table 19, Global Warming Potentials in Table 24, emissions of N_2O during the production of N-fertilisers in Table 46. Emissions per kg obtained by dividing the emissions per capita by the consumed amounts in Table 1.

Table 48: Emissions in CO_2 equivalents during production and transportation of the fertilisers needed for the consumed amounts of tomatoes. According to countries of consumption origin. In g per capita and year and g per kg. [220]

Country of consumption origin	Type of fertiliser	Emissions expressed in CO_2 equivalents			
		20-year perspective		100-year perspective	
		g CO_2 per capita and year	g CO_2 per kg	g CO_2 per capita and year	g CO_2 per kg
Denmark	N	19	42	20	45
	P	0,46	1,0	0,46	1,0
	K	2,0	4,4	1,98	4,4
Denmark total		21	48	23	50
Netherlands	N	52	19	55	21
	P	1,5	0,57	1,52	0,57
	K	6,0	2,2	6,0	2,2
Netherlands total		59	22	63	23
Spain	N	350	170	380	180
	P	19	9,3	19	9,3
	K	32	16	32	16
Spain total		410	200	430	210
Sweden	N	73	42	77	44
	P	1,8	1,0	1,8	1,0
	K	7,6	4,4	7,6	4,4
Sweden total		82	47	86	50
"Other countries"	N	49	190	52	200
	P	2,5	9,5	2,5	9,5
	K	4,0	16	4,0	16
"Other countries" total		55	210	58	220
Total per capita/average per kg		**620**	**86**	**660**	**91**

33. All energy requirements †

Table 49 shows the energy requirements for the consumed amounts of carrots and tomatoes during transportation, storage, farm production and production and transportation of fertilisers.

[220] Recommended doses of fertilisers in Table 36, emissions from fertiliser production in section 29 and Table 44, transported (and produced) amounts in Table 20, Global Warming Potentials in Table 24, emissions of N_2O during the production of N-fertilisers in Table 46. Emissions per kg obtained by dividing the emissions per capita by the consumed amounts in Table 1.

Table 49: Energy requirements for the consumed amounts of carrots and tomatoes during transportation, storage, farm production and production and transportation of fertilisers. According to countries of consumption origin. In MJ per capita and year and MJ per kg. Including pre-combustion energy requirements. [221]

Country of consumption origin	Source of energy requirements	Energy requirements			
		Carrots		Tomatoes	
		MJ per capita and year	MJ per kg	MJ per capita and year	MJ per kg
Denmark	transportation	0,26	1,00	0,41	0,92
	storage	0,071	0,27	0,076	0,17
	farm production	0,20	0,76	26	59
	production of fertilisers	0,045	0,17	0,12	0,27
Denmark total		0,58	2,2	27	60
Netherlands	transportation	0,49	1,75	4,8	1,8
	storage	0,090	0,32	0,45	0,17
	farm production	0,18	0,65	150	56
	production of fertilisers	0,027	0,095	0,33	0,12
Netherlands total		0,80	2,8	155	58
Germany	transportation	0,041	1,40		
	storage	0,092	0,31		
	farm production	0,019	0,65		
	production of fertilisers	0,0043	0,15		
Germany total		0,07	2,5		
Great Britain	transportation	0,023	1,16		
	storage	0,0064	0,33		
	farm production	0,013	0,66		
	production of fertilisers	0,0029	0,15		
Great Britain total		0,045	2,29		
Italy	transportation	0,46	3,17		
	storage	0,048	0,33		
	farm production	0,10	0,66		
	production of fertilisers	0,022	0,15		
Italy total		0,63	4,3		
Spain	transportation			7,4	3,5
	storage			0,38	0,18
	farm production			0,85	0,41
	production of fertilisers			2,3	1,1
Spain total				11	5

continued...

221 Added energy requiremnents from Table 21, 29-30, 38 and Table 45.

Country of consumption origin	Source of energy requirements	Energy requirements			
		Carrots		Tomatoes	
		MJ per capita and year	MJ per kg	MJ per capita and year	MJ per kg
Sweden	transportation	4,9	0,81	1,4	0,78
	storage	1,6	0,27	0,24	0,14
	farm production	4,3	0,71	100	58
	production of fertilisers	0,97	0,16	0,46	0,26
Sweden total		12	2,0	100	60
"Other countries"	transportation	0,13	3,16	0,74	2,9
	storage	0,016	0,40	0,053	0,20
	farm production	0,041	1,0	0,12	0,47
	production of fertilisers	0,0094	0,24	0,33	1,3
"Other countries" total		**0,19**	**4,8**	**1,2**	**4,8**
Total per capita /average per kg		**14**	**2,1**	**300**	**41**

34. All emissions in CO_2 equivalents ©

Table 50 and Table 51 shows the emissions in CO_2 equivalents for the consumed amounts of carrots and tomatoes during transportation, storage, farm production and production and transportation of fertilisers.

Table 50: Emissions in CO_2 equivalents for the consumed amounts of carrots during transportation, storage, farm production and production and transportation of fertilisers. According to countries of consumption origin. In g per capita and year and g per kg. [222]

Country of consumption origin	Source of emissions	Emissions expressed in CO_2 equivalents			
		20-year perspective		100-year perspective	
		g CO_2 per capita and year	g CO_2 per kg	g CO_2 per capita and year	g CO_2 per kg
Denmark	transportation	22	85	22	85
	storage	46	180	30	110
	farm production	30	110	31	120
	production of fertilisers	8,1	31	8,5	32
Denmark total		110	400	90	350
Netherlands	transportation	42	150	42	150
	storage	67	240	35	120
	farm production	23	80	23	81
	production of fertilisers	4,8	17	5,0	18
Netherlands total		136	482	105	371
Germany	transportation	3,5	120	3,5	120
	storage	7,0	240	3,7	130
	farm production	2,6	90	2,7	92
	production of fertilisers	0,77	26	0,81	28
Germany total		14	475	11	366
Great Britain	transportation	2,1	100	2,0	100
	storage	4,9	250	2,7	140
	farm production	1,7	89	1,8	91
	production of fertilisers	0,52	27	0,54	28
Great Britain total		9	477	7	361
Italy	transportation	39	270	39	270
	storage	36	240	19	130
	farm production	13	87	13	89
	production of fertilisers	3,9	27	4,1	28
Italy total		92	626	76	517
Sweden	transportation	420	70	430	70
	storage	630	100	270	44
	farm production	480	79	490	82
	production of fertilisers	170	28	170	29
Sweden total		1700	280	1400	230

continued...

222 Added emissions from Table 25, 33, 41 and 47.

Country of consumption origin	Source of emissions	Emissions expressed in CO_2 equivalents			
		20-year perspective		100-year perspective	
		g CO_2 per capita and year	g CO_2 per kg	g CO_2 per capita and year	g CO_2 per kg
"Other countries"	transportation	11	270	11	270
	storage	12	300	7	160
	farm production	6,5	150	6,7	150
	production of fertilisers	1,4	35	1,5	37
"Other countries" total		31	760	25	630
Total per capita/ average per kg		**2100**	**310**	**1700**	**250**

Table 51: Emissions in CO_2 equivalents for the consumed amounts of tomatoes during transportation, storage, farm production and production and transportation of fertilisers. According to countries of consumption origin. In g per capita and year and g per kg. [223]

Country of consumption origin	Source of emissions	Emissions expressed in CO_2 equivalents			
		20-year perspective		100-year perspective	
		g CO_2 per capita and year	g CO_2 per kg	g CO_2 per capita and year	g CO_2 per kg
Denmark	transportation	35	78	35	78
	storage	38	84	25	55
	farm production	2400	5100	2400	5100
	production of fertilisers	21	48	23	50
Denmark total		2500	5600	2500	5600
Netherlands	transportation	410	150	410	150
	storage	160	71	100	42
	farm production	10000	3600	10000	3600
	production of fertilisers	59	22	63	23
Netherlands total		11000	4100	11000	4000
Spain	transportation	660	300	620	300
	storage	140	67	79	38
	farm production	470	230	520	250
continued....	production of fertilisers	410	200	430	210

223 Added emissions from Table 26, 34, 42 and 48.

Country of consumption origin	Source of emissions	Emissions expressed in CO_2 equivalents			
		20-year perspective		100-year perspective	
		g CO_2 per capita and year	g CO_2 per kg	g CO_2 per capita and year	g CO_2 per kg
Spain total		1700	810	1600	790
Sweden	transportation	120	68	120	69
	storage	66	38	29	17
	farm production	7000	3800	7000	3800
	production of fertilisers	82	47	86	50
Sweden total		7200	4200	7200	4200
"Other countries"	transportation	66	240	66	240
	storage	170	640	68	260
	farm production	68	260	74	290
	production of fertilisers	55	210	58	220
"Other countries" total		360	1400	270	1000
Total per capita/ average per kg		**23000**	**3100**	**22000**	**3100**

35. Sensitivity Analysis

The variables for the sensitivity analysis were chosen because, either the values in the base-line study were considered as rather unreliable, or because these values may change in the near future. Examples of such changes are increased energy efficiency and a substitute of refrigerants. The ranges of the sensitivity analysis were chosen somewhat arbitrarily because of the lack of knowledge about possible variations of the chosen parameters in the base-line study.

The variables tested in the sensitivity analysis are listed below. The results were compared to the total impacts (per capita and year and per kg consumed product) from carrots and tomatoes as they were presented in Table 50 and 51. The figures within brackets are the ranges of the sensitivity analysis.

1) Energy requirements for transportation with lorries (± 50 %, base-line assumptions in table 17)

2) Energy requirements for transportation with planes (± 50 %, tomatoes only, base-line assumptions in section 9.c)

3) a. mode of transportation for tomatoes from the Canary Islands in Spain (20 % of the tomatoes by air-craft, 30 % of the tomatoes by boat from the Canary Islands as opposed to the assumptions in the base-line study which was 1 % of the tomatoes by air-craft and 49 % by boat from the Canary Islands)

b. mode of transportation for tomatoes from the Canary Islands in Spain (0 % of the tomatoes by air-craft, 50 % of the tomatoes by boat from the Canary Islands as opposed to the assumptions in the base-line study which was 1 % of the tomatoes by plane and 49 % by boat from the Canary Islands)

4) rate of emissions from transport refrigeration equipment in lorries (± 50 %, base-line assumptions in section 11.a)

5) GWP for the refrigerant in transport refrigeration equipment in lorries (± 50 %, base line assumptions were 7900 (20-years perspective) and 8500 (100-years perspective, see Table 24.)

6) number of days in storage (± 50 %, carrots only, base-line assumptions in Table 29)

7) number of days when storage facilities for long-term storage are used per year (± 35 %, carrots only, base-line assumption is section 18.a)

8) rate of emissions from storage rooms (± 50 %, base-line assumptions in section 18)

9) use of fuel for running farm implements (± 50 %, base-line assumptions in section 22.b)

10) N_2O emission rates from farm land (± 50 %, base-line assumptions in section 24).

11) Use of fuel for heating greenhouses (± 50 %, tomatoes only, base-line assumptions in section 22 c)

12) need of electricity for irrigation (± 50 %, carrots only, base-line assumptions in section 22.b)

13) energy requirements for the production and transportation of fertilisers (± 50 % base-line assumptions in section 28)

The results of the sensitivity analysis are shown in Table 52 (below).

Table 52: Results from a sensitivity analysis of emissions of greenhouse gases (expressed in CO_2 equivalents) from the consumed amounts of carrots and tomatoes. 14 variables tested. Variations from the base-line results of the total capita^{-1} * year^{-1} and kg^{-1} emissions expressed as % deviation.

Parameter	Carrots		Tomatoes	
	20-years perspective,	100-years perspective,	20-years perspective	100-years perspective
1	± 12 %	± 15 %	±2.3 %	±2.3 %
2			<1.0 %	<1.0 %
3 a			+6.9 %	+ 7.0 %
3 b			<- 1.0 %	<- 1.0 %
4	< 1.0 %	< 1.0 %	<1.0 %	<1.0 %
5	< 1.0 %	< 1.0	<1.0 %	<1.0 %
6	±18 %	±10 %		
7	± 7.9 %	± 3.9 %		
8	±18 %	±8.7 %	<1.0 %	<1.0 %
9	±8.1 %	±10 %	<1.0 %	<1.0 %
10	±4.5 %	±6.2 %	± 1.4 %	± 1.5 %
11			± 43 %	± 43 %
12	<1.0 %	<1.0 %		
13	±2.2 %	±2.8 %	<1.0 %	<1.0 %

* The category < 1 % means that the changes were smaller than 1 % whether on the negative or positive side.

The sensitivity analysis shows that both emission profiles are quite insensitive to any changes in the transport refrigeration equipment by, for example, lowering the emission rates of refrigerants or using refrigerants with lower Global Warming Potentials. The impact profiles are also rather insensitive to increased energy efficiency for fertiliser production and transportation, transportation by plane or irrigation.

The carrot impact profile is most sensitive to changes in the use or handling of the storage equipment. If the storage facilities for long-term storage are utilized to a higher extent, then the emissions decrease by 8 % in a 20-years perspective. While changes in emissions rates from storage rooms and a shorter storage time are equally important and would each contribute to an 18 % decrease. The carrot impact profile is also quite sensitive to changes in the energy requirements for farm implements and lorries. The same is the case with more efficient practices for fertiliser application, with the aim of lowering the share of N-fertiliser emitted as N_2O from farm land.

The tomato impact profile is sensitive to changes in only two variables. These two variables are the energy requirements for heating greenhouses and the mode of transportation for tomatoes from the Canary Islands, Spain. When energy requirements for heating greenhouses are halved, impacts drop by 43 %. If the quantity of tomatoes transported by plane from the Canary Islands increases to 0,43 kg* capita^{-1} * year^{-1}, instead of 0,02 kg capita^{-1} *year^{-1}, emissions increase by 7 %.

36. Key-issues in the life-cycle of the studied products

Four stages during the life-cycle of carrots and tomatoes were studied: production of fertilisers, farm production, storage and transportation. Emissions during these stages were caused by fuel combustion, leaking refrigerants, and N_2O (as a result of application of N-fertilisers on farmland and process emissions of N_2O during the production of N-fertilisers). The key-issues concerning emissions of greenhouse gases are discussed here.

Key-issues in the life-cycle of carrots

Storage contributes with 37 to 53 % of the total emissions during the life-cycle of carrots, while transportation accounts for 21 to 43 %, farm production for 14 to 28 %, and the production and transportation of fertilisers for 4 to 10 % as is shown in Table 53. Storage may therefore be considered as the most important stage during the studied part of the life-cycle.

Table 53: Relative contributions from different stages to emissions in CO_2 equivalents during the life-cycle of carrots. In relative share of the total emissions per capita and year with a 20-years time perspective. [224]

Stages	Denmark	Nether-lands	Germany	Great Britain	Italy	Sweden
storage	0,43	0,49	0,50	0,53	0,39	0,37
transportation	0,21	0,31	0,25	0,23	0,43	0,25
farm production	0,28	0,17	0,19	0,19	0,14	0,28
production of fertilisers	0,08	0,04	0,06	0,06	0,04	0,10

Emissions were mainly caused by combustion of fuels followed by leaking of refrigerants, as can be seen in Table 54. Fuel combustion for various purposes (running lorries, farm implements as well as generating electricity) contributed to 48 to 63 % of the total emissions while refrigerants contributed to 26 to 42 % of the total emissions. Emissions of N2O contributed with but 5 to 15 % of the total emissions.

Table 54: Relative contributions from refrigerants, fuel combustion and N_2O during the life-cycle of carrots. In relative share of the total emissions per capita and year with a 20-years time perspective. Emissions of CH_4 during electricity generation by hydro power have been excluded because they were negligible. [225]

Stages	Denmark	Nether-lands	Germany	Great Britain	Italy	Sweden
refrigerants	0,26	0,40	0,41	0,42	0,32	0,37
fuel combustion	0,63	0,55	0,51	0,50	0,62	0,48
N_2O	0,11	0,05	0,08	0,08	0,06	0,15

During storage, almost all emissions were caused by leaking refrigerants. The proportion of CO_2 equivalents from refrigerants during storage is shown in Table 55.

224 Based on Table 50, g CO_2 equivalents per capita and year, 20-years time perspective.

225 Based on Table 25, 33, 41 and 47.

Table 55: Relative contributions from refrigerants and electricity generation to emissions in CO_2 equivalents during storage of carrots. In relative share of the total emissions per capita and year during storage with a 20-years time perspective. [226]

Storage	Denmark	Nether-lands	Germany	Great Britain	Italy	Sweden
Electricity	0,42	0,21	0,22	0,26	0,23	0,05
Refrigerants	0,58	0,79	0,78	0,74	0,77	0,95

As was pointed out in section 18, information about leakage of refrigerants from storage rooms was scarce and need to be revised in further analysis. This point is further underlined by the results presented in Table 53 to 55. Leakage's of refrigerants during storage may be the key-issue in the life-cycle of carrots, and possibly in the life-cycle of other vegetables cultivated in the open and stored for long stretches of times as well.

Transportation, was, after storage, an important stage of the life-cycle for carrots. For Italian carrots, it was the most important stage, thus indicating that, at some distance between the Netherlands and Italy there is a breaking point where emissions from transportation outweighs all other emissions. With present consumption patterns, carrots are however mostly imported from countries of consumption origin closer to Sweden than Italy (see section 4.e) with the exemption of USA and Israel. From the two latter countries, carrots may be however be shipped with low energy requirements per kg-km when compared to transportation with lorries (see Table 17 and 18). Therefore, with present consumption patterns for carrots, transportation is probably almost never the key-issue.

Key-issues in the life-cycle of tomatoes

The studied tomatoes were produced in two different cropping systems: highly intensive ones (Denmark, Netherlands and Sweden) and low-intensive cropping systems (Spain and other countries).

Farm production contributes to 94 to 96 % of the total emissions during the life-cycle of tomatoes in high intensive cropping systems. For low intensive cropping systems, farm production contributed with but 28 %. This latter share is of about the same magnitude as for carrots (Table 53). Transportation contributed to 1-4 % for high intensive cropping systems, but for low intensive cropping systems the same contribution was 39 %. The contributions from storage was low for high intensive cropping systems (2 % or less), and rather low for tomatoes from Spain (8 %). The production of fertilisers contributed with a substantial share in low intensive cropping systems (24 %), while the contribution in intensive cropping systems were negligible (1 %). The relative contributions from all stages during the life-cycle of tomatoes are shown in Table 56.

[226] Based on Table 33, g CO_2 equivalents per capita and year, 20-years time perspective.

Table 56: Relative contributions from different stages to emissions in CO_2 equivalents during the life-cycle of tomatoes. In relative share of the total emissions per capita and year with a 20-years time perspective. [227]

Stages	Denmark	Nether-lands	Spain	Sweden
storage	0,02	0,01	0,08	0,01
transportation	0,01	0,04	0,39	0,02
farm production	0,96	C,94	0,28	0,96
production of fertilisers	0,01	0,01	0,24	0,01

Emissions were mainly, or almost entirely, caused by combustion of fuels, as can be seen in Table 57. Fuel combustion for various purposes (running lorries, farm implements as well as generating electricity) contributed to 97-98 % in high intensive cropping systems and to 55 % in low intensive cropping systems. Emissions of N_2O contributed with 36 % of the total emissions in low-intensive cropping systems.

Table 57: Relative contributions from refrigerants, fuel combustion and N_2O during the life-cycle of tomatoes. In relative share of the total emissions per capita and year with a 20-years time perspective. Emissions of CH_4 during electricity generation by hydro power have been excluded because they were negligible. [228]

Stages	Denmark	Nether-lands	Spain	Sweden
refrigerants	0,01	0,01	0,09	0,01
fuel combustion	0,98	0,98	0,55	0,97
N_2O	0,01	0,01	0,36	0,02

As was pointed out in section 22 c, estimates about the need of energy for heating greenhouses differ. Information about the need of energy for heating greenhouses should therefore be revised in further analysis. This point is further underlined by the results presented in Table 56 to 57. Energy requirements for farm production is a key-issue in high intensive cropping systems for tomatoes, and possibly in the life-cycle of other vegetables with short duration cultivated in greenhouses as well.

Key issues for tomatoes in low intensive cropping systems are transportation and farm production. It is possible that transportation is the key-issue for such tomatoes with present Swedish consumption patterns. Section 4 e showed that , tomatoes from 27 "other countries" were imported. Many of these countries were situated far away from Sweden and some of the tomatoes must have been transported by plane with high energy requirements per kg-km when compared to transportation with lorries and ships (see Table 17 and 18 and section 9.c). Therefore, with present consumption patterns for tomatoes, transportation is probably the key-issue when the tomatoes are cultivated in the open.

The general conclusions from the study of carrots and tomatoes are as follows:

* The key-issue for vegetables with a long durability may be storage if the vegetables are adapted to a northern European climate.

[227] Based on Table 51, g CO_2 equivalents per capita and year, 20-years time perspective.

[228] Based on Table 26, 34, 42 and 48.

*The key-issue for vegetables with a short durability may be transportation if the vegetables are not adapted to a northern European climate but still cultivated in the open.

* The key-issue for vegetables with a short durability may be energy requirements during farm production if th vegetables are not adapted a northern European climate and therefore cultivated under glass.

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