CO_2 Emission in the Fresh Vegetables Chains: A Meta-Analysis

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Abstract

Carbon footprint has become a widely used term and concept in the public debate on social responsibility towards a sustainable future. Carbon emissions reduction target represents a global challenge gaining the headlines around the world and pushing academic scientists to discuss actively possible technical innovations, economic consequences and environmental benefits. On the other hand consumers already have recognized a clear willingness to buy for the environmental and ethical dimensions of food products and policies for the primary sector, at the same time, have driven the above-described dynamics with greater resolution, recognizing the potential for an effective response to the squeeze in farm profit margins, supporting producers in their effort to leave the perimeter of commodities. However, Carbon footprint estimates largely differ across the literature, even though they refer to the same product, involving the same production processes. The present paper addresses explicitly the latter drawback, implementing a meta-analysis focused on fresh vegetables chain. The objective is assessing the uncertainty of `Carbon footprint' estimates, seeking a meaningful statistical description of the findings of a vast collection of studies. Our results show the large estimates variability across empirical studies and how they these estimates largely depend by certain study-specific characteristics, like methodology adopted.

Keywords: *carbon footprint; fresh vegetables chain; meta-analysis*

1 Introduction

Carbon emission was, till about twenty years ago, one of those subjects debated almost exclusively among scientists. When scholars related carbon emissions to a worldwide issue, such as global warming, this subject became more and more popular. The public aware about global warming was officialised thanks to the United Nations Framework Convention on Climate Change (UNFCCC). UNFCCC was born from the Rio Earth Summit, and came in force in 1994 when 192 countries ratified it. One of its main objectives was the stabilization of the concentration of greenhouse gas emissions aiming to a decrease of the so called global warming. The operational tool of the UNFCCC has been the Kyoto protocol (1997) that binds the 182 ratifying countries to reduce the emission of greenhouse gases. Since 1997 several other agreements have been arranged. However, one of the uncontroversial results was that voluntary individual initiatives have been taking place. As a consequence a measure of the carbon emission, namely carbon footprint, has been becoming a widely used term and concept in the public debate on social responsibility towards a sustainable future. The increased environmental awareness is affecting the food supply chain as well. Consumers have already recognized a clear willingness to buy for the environmental and ethical dimensions of food products. These are a sort of dimensions that are playing a key role also in consumer segmentation. Policies for the primary sector, at the same time, have driven the above-described dynamics with greater resolution, recognizing the potential for an effective response to the squeeze in farm profit margins, supporting producers in their effort to leave the perimeter of commodities (Caracciolo *et al.*, 2010).

The appeal for social responsibility calls for an increase in efforts to create sustainable products, which must be satisfied and encouraged, but also to seek solutions that raise sustainability standards, achieving a clear market recognition by consumers. Carbon footprint labelling allows consumers to participate directly in the mentioned dynamics, being a quantitative expression of green houses gases emissions from an activity (Finkbeiner, 2009).

To calculate the carbon footprint, the amount of greenhouse gases emitted, or removed, embodied in the life cycle of the product must be estimated. Generally this measurement includes all the steps involved in manufacturing a product as its right to bring raw materials to final packaging, distribution, consumption/use, and for the final disposal. However, despite its rising appearance there is still a certain degree of confusion on what it actually means and measures (Pandey *et al.*, 2011). From an empirical point of view, the quantification may be sensitive to researcher choices, to assumptions on key parameters and to the accuracy of input data. Overall great uncertainty exist in results and the scientists are still debating on the right emissions quantification due the these limitations (Lo *et al.*, 2005). Therefore, carbon footprint estimates largely differ across the literature, even though they refer to the same product, involving the same production processes.

The present paper tries to explicitly address the latter drawback, implementing a meta-analysis focused on fresh vegetables chain. Meta-analysis have been developed in early '900 (Pearson, 1904) but in recent decades this method of investigation has established itself as a very useful tool to explore in an objective, and efficient way bodies of literature particularly wide. Meta-analysis technique is common to many fields of research. The main field of application is that of medical research, but also in other fields, such as Economics, had considerable success. The study discussed hereafter seems to be the first meta-analysis concerning the Carbon Footprint in fresh vegetable production. The objective is to assess the uncertainty of carbon footprint estimates, seeking a meaningful statistical description of the findings of a vast collection of studies. The paper is organized as follows. After a brief review on the statistical model used in meta-analysis (section 2), in section 3 information on the surveyed articles and main variables collected are provided, followed by the presentation of the results (section 4), and by a brief discussion about the main findings of the research (section 5).

2 Empirical Model

The goal of this meta-analysis is to generate a set of findings about Carbon Footprint in fresh vegetables products that are not conditional on the particulars of a single study, and to provide researchers a concise summary of the extant works. In fact, meta-analysis allows to examine the extent of carbon footprint despite different study conditions, like different research designs, methodologies, food products and stages of the food chain involved.

The most commonly used statistical techniques of meta-analysis are: 1. Simple regression models 2. Fixed Effect Models, and 3. Random Effect Models.

The last two techniques are particularly useful when the object of the different studies is the estimation of an "effect size" from the observations coming from a specific sample (effectiveness of a drug, willingness to pay a premium price for an organic product, etc.). In the current study, if the variances of the different parameters had been estimated and, then, were available it would have been possible to identify a "true effect size" or "more true effects size" coming from different research sources. Unfortunately, that is not the case. The literature concerning carbon footprint generates, due to the phenomena observed in nature, deterministic based values. For this reason models, such as "fixed effect models" or random effect model", are not applicable. Model applied was an ordinary least. In detail, we assume that study i of a total n studies provides an estimate y_i of the CO_2, around the linear predictor:

$$y_i = \mathbf{x}_i \boldsymbol{\beta} + u_i, \text{ where } u_i \sim N(0,\sigma^2)$$

where, $\mathbf{x}_i$ is a $1 \times k$ vector of covariates values (including the constant) characterizing the study i and $\boldsymbol{\beta}$ is a $k \times 1$ vector of covariates coefficients. In order to prevent heterosckedasticity bias, standard errors were bootstrapped.

3 Data source and definition

A meta-analysis requires, as very first step, a particular care in selecting and collecting papers and scientific reports concerning the subject in hand. One of the first issue to address is the period of time over which the literature review is done. There is no formal way to proceed. However, a good hint is provided by some statistics available in Google. In figure 1 searches on Google since 2004 for "CO_2 emissions" and "carbon emissions" are reported. In figure 2, for the same period of time, are reported the number of searches on Google for "carbon foot print". Lastly, in table 1 Google scholar references from 1990 to 2011 on "carbon foot print" are listed. The combined reading of these three trends shows how and when the key words taken into account became popular worldwide, first searching the web and then producing scientific reports and/or articles. Even though number of references started to become significant numerous since 2005, the literature review implemented in this paper started since December 1997.

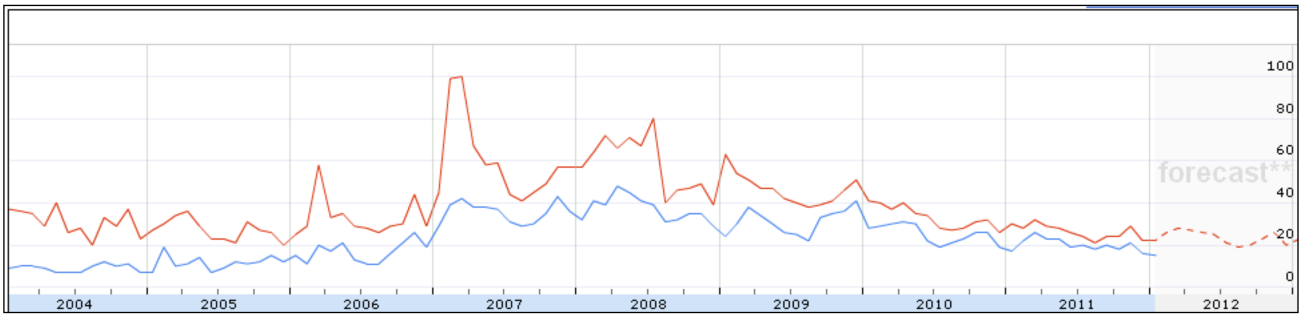

Figure 1. Searches done on Google over time for "co2 emission" and "Carbon emission"

Literature on CO_2 emission topic was searched and analysed. Another relevant decision to take when approaching a meta-analysis concerns the key words for computer searches. They were: LCA (Life Cycle Assessment), carbon footprint, CO_2 emission, carbon footprint estimates, carbon emission, climate change, greenhouse gas emissions. Such searches were done plugging in once at a time each of the key words in the widest databases reporting papers and scientific reports.

Figure 2. Searches done on Google over time for "Carbon foot print"

Table 1.
Google scholar references per year, “Carbon foot print”.

Year	Hits	Year	Hits
1990	4	2001	40
1991	4	2002	69
1992	4	2003	65
1993	3	2004	69
1994	6	2005	106
1995	8	2006	240
1996	10	2007	1,310
1997	6	2008	3,600
1998	18	2009	5,600
1999	22	2010	7,360
2000	25	2011	7,050

Since the focus of the research was carbon emissions of fresh vegetables, only papers reporting explicitly kg CO_2 emission per kg of product were saved and took into consideration. Other data was also collected such as emissions per processing phase divided in production, transportation and consumption. It was also collected information, when available, on either the production was organic or conventional. In Appendix 1 the 92 observation collected are organized in a matrix.
Although we are aware that a complete literature review is almost impossible, we feel confident that papers analysed give more than a hint of the data available. Nevertheless, the real “danger” resides in ‘file drawer problem’ (Bengtsson, Ahnström and Weibull, 2005). The complete list of collected variables (Appendix 1) is: kg CO_2/ per kg of product, author/s, year of publication, journal title, type of publication, analysis location, approach typology (micro/macro, deterministic/stochastic), product involved, food chain stages, number of citations.

4 Meta-analysis results

The hypothesized model originally included all the variables collected from the papers, since they are considered relevant in explaining the observed variation in estimation of CO_2.
Regressors can be grouped as referring to “scientific type and information of publication”, “food chain stage”, and “type of analysis” (Tab. 2).

Table 2.
Summary statistics and definitions of variables

			Mean	Std. Dev.
	CO_2	CO_2	0.899	1.748
Type of publication	**Peer Review**	PRP	0.391	0.491
	Conference paper	COP	0.217	0.415
	Report	REP	0.217	0.415
Info publication	Year of Publication	YEA	2007 (*median*)	
	Citation #	CIT	19.5	30.241
	Production	PRO	0.902	0.299
	Storage	STO	0.141	0.350
Food Chain stage	**Transport**	TRA	0.783	0.415
	Packaging	PAC	0.261	0.442
	Consumption	CON	0.098	0.299
	Deterministic	DET	0.815	0.390
Type of analysis	**Stochastic**	STO	0.185	0.390
	Micro	MIC	0.554	0.500
	Macro	MAC	0.446	0.500
	Potatoes	POT	0.163	0.371
	Carrot	CAR	0.130	0.339
	Onion	ONI	0.054	0.228
	Lettuce	LET	0.087	0.283
	Pumpskins	PUM	0.011	0.104
	Tomato	TOM	0.217	0.415
	Apple	APP	0.076	0.267

Notes: in bold the variables included in the model

The final model followed the criterion with which variables defined in the above table enter the model only if the estimated coefficients are statistically significant (at least 5%), avoiding at the same time any "dummy variable trap" which is one of the possible drawback when most of the explanatory variables are dummies. Therefore, the implemented model is:

$$\textit{log}\ (CO_2)_i = \beta_1 + \beta_2\ PRP_i + \beta_3\ COP_i + \beta_4\ PRO + \beta_5\ TRA + \beta_6\ CON + \beta_7\ STO + \beta_8\ POT + \beta_9\ CAR + \beta_{10}\ ONI + u_i$$

Meta-analysis results, applying OLS estimation on the above model, are reported in Table 3. Estimated coefficients are all statistically significant at least at 5% of significance. In order to maximize the model goodness of fit, a log transformation of the dependent variable was done before running the model. In figure 3 a Kernel density estimate is reported showing the appropriateness of the transformation. This procedure, widely used in the literature, results to be equally efficient compared with the estimate using the dependent variable expressed in its level. However, estimated coefficients cannot be considered directly as marginal effect. For this reason a re-transformation of the estimated coefficients was performed obtaining, in this way, the average marginal effects of the explanatory variables (Tab. 4).

Table 3.
Meta-analysis results

Dep. var: log(kg CO_2/kg of product) *Obs. 86*
F(9, 76): 10.27 *Prob > F: 0.000*
R-squared: 0.54 *Root MSE: 0.9721*

log (Kg CO_2/Kg)	Coef.	t
Peer Review (PRP)	-1.17***	-3.41
Conference paper (COP)	-0.76 **	-2.47
Production (PRO)	1.51***	4.13
Transport (TRA)	0.90***	2.88
Consumption (CON)	0.78 **	1.96
Stochastic (STO)	1.62***	4.37
Potatoes (POT)	-1.28***	-3.85
Carrot (CAR)	-1.12***	-3.36
Onion (ONI)	-1.58***	-3.28
Constant	-2.53***	-5.13

*Level of significance: *** 1%; ** 5%*

Interpretation of marginal effects is straightforward. A first result concerns data sources. When a carbon footprint estimate is reported in papers subject to peer review (PTP) or in proceedings of conferences (COP) they tend to be smaller. Looking at this result on the other way around, data reported on scientific report, with no peer review, overestimate carbon footprint calculation.
A second result to be underlined regards differences among fresh vegetables. Production of onions appears to produce the least carbon footprint (-0.52) compared with all the other vegetables collected. It is followed by potatoes (-0.48) and carrots (-0.45).
The most relevant result, however, concerns the marginal effects calculated at the three main clusters of the agro-food chain: production, transportation, and consumption. As expected, estimated coefficients are all positive but the transportation phase is the least influencing the total amount of carbon emissions.

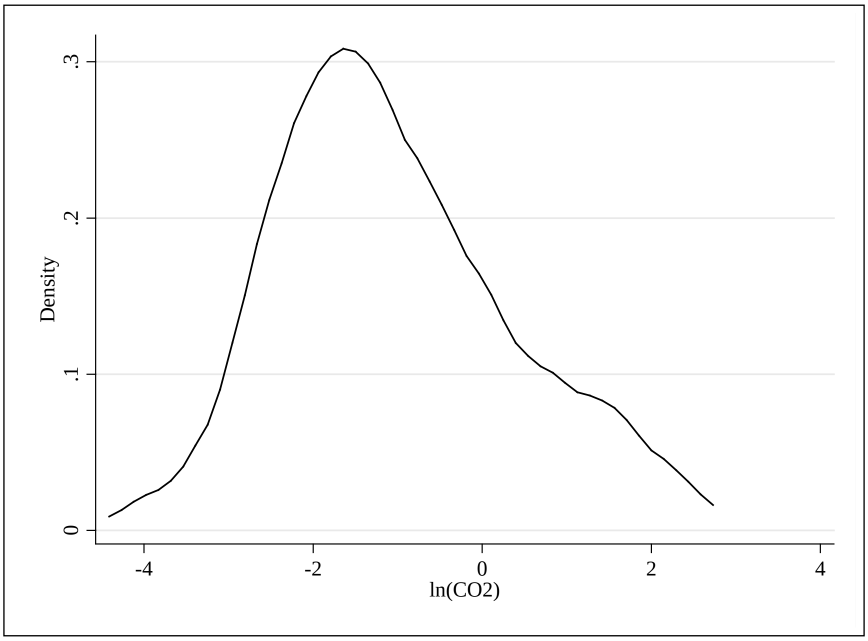

Figure 3. Kernel density estimate *log*($KgCO_2$/Kg)

Table 4.
Average Marginal effects after transformation

(from log to level)

	Average Effect (Kg CO_2/Kg)
Peer Review (PRP)	-0.46
Conference paper (COP)	-0.39
Production (PRO)	+0.56
Transport (TRA)	+0.39
Consumption (CON)	+0.42
Stochastic (STO)	+0.79
Potatoes (POT)	-0.48
Carrot (CAR)	-0.45
Onion (ONI)	-0.52

5 Concluding remarks

The main findings of this research are discussed already in the previous section. However, it is worth remarking some of them trying to reason on the implications that our results might have on further research.

As first remark we have to notice that the literature review done for this paper, though quite wide, is far from being complete. More articles and/or scientific reports could add more details to what we can consider a puzzle of carbon footprint studies.

Staying with our results, a finding that has to be taken into account when using calculation coming from literature is that not all we find available as references is of the same quality. Journal articles, subjected to peer review, seems to be more trustful, followed by conference proceedings.

Another thing worth noting regards the use of meta-analysis results like the one here performed. It happens, several times, to read articles where some parameters, such as carbon footprint calculation, is exogenous. For example, if one needs to estimate the environmental impact of a certain set of products along with a chain, but in a wider economic model, many parameters are implemented in that model after a literature review. This procedure is wide used but has a massive amount of subjectivity related to the choice made by the researcher. Many times, however, such parameters have no confidence interval reported because they are itself calculated by means of a deterministic equation. A meta-analysis allows to attach to the mean values calculated confidence intervals that are more appropriate when implemented stochastic modelling procedures.

The very last thing, more political to some extent, is the result of the coefficients related to the chain subdivided into three stages. When talking of reducing the impact of the CO_2 in the agro-food sector, most of the times scholars debate on how to make more efficient the transportation. Based on our results, transportation affect the total carbon footprint less than consumption and much less than production. Other strategies should be taking in place approaching the problem in a different way.

APPENDIX 1

CO_2/ kg	Authors	Year of Publication	Journal	Type of pubblication	Analysis location	Macro/micro approach	Deterministic/ Stochastic	Product Involved	Food chain stages	Number of Citations
-0.24	Koerber, Jones, Hill, Milà i Canals, Nyeko, York and Jones	2009	Journal of Applied Ecology	Peer review	UK	micro	deterministic	Lettuce	production	7
-0.24	Koerber, Jones, Hill, Milà i Canals, Nyeko, York and Jones	2009	Journal of Applied Ecology	Peer review	UK	micro	deterministic	Potato	production	7
-0.16	Koerber, Jones, Hill, Milà i Canals, Nyeko, York and Jones	2009	Journal of Applied Ecology	Peer review	UK	micro	deterministic	Potato	production	7
-0.16	Koerber, Jones, Hill, Milà i Canals, Nyeko, York and Jones	2009	Journal of Applied Ecology	Peer review	UK	micro	deterministic	Potato	production	7
-0.11	Koerber, Jones, Hill, Milà i Canals, Nyeko, York and Jones	2009	Journal of Applied Ecology	Peer review	Uganda	micro	deterministic	Broccoli	production	7
-0.05	Koerber, Jones, Hill, Milà i Canals, Nyeko, York and Jones	2009	Journal of Applied Ecology	Peer review	Spain	micro	deterministic	Lettuce	production	7
0.02	Tzilivakis, Warner, May, Lewis, Jaggard	2004	Agricultural Systems	Peer review	UK	micro	deterministic	sugar beet	production	63
0.03	O'Halloran, Fisher and Rab	2008	Horticulture Australia Limited (HAL)	Conference Paper	Australia	micro	deterministic	Beetroot	production - transport	2
0.04	Koerber, Jones, Hill, Milà i Canals, Nyeko, York and Jones	2009	Journal of Applied Ecology	Peer review	UK	micro	deterministic	Broccoli	production	7
0.04	Mason, R., Simons, D. Peckham, C., & Wakeman, T	2002	Department of Transport, UK	Report	UK & Spain	macro	deterministic	Lettuce	transport	7
0.07	Van Hauwermeiren, A., Coene, G., Engelen, G., & Mathijs, E.	2007	Journal of Environmental Policy and Planning	Report	Belgium	micro	deterministic	Apple	transport	26
0.07	Fogelberg, C. & Carlsson-Kanyama, A.	2006	Swedish Defence Agency (FOI)	Report	Sweden	macro	deterministic	Carrot	production - packaging - transport	2
0.07	Fogelberg, C. & Carlsson-Kanyama, A.	2006	Swedish Defence Agency (FOI)	Report	Sweden	macro	deterministic	Onion	production - packaging - transport	2
0.08	Van Hauwermeiren, A., Coene, G., Engelen, G., & Mathijs, E.	2007	Journal of Environmental Policy and Planning	Report	Belgium	micro	deterministic	Potato	transport	26
0.08	Koerber, Jones, Hill, Milà i Canals, Nyeko, York and Jones	2009	Journal of Applied Ecology	Peer review	Uganda	micro	deterministic	Lettuce	production	7
0.09	O'Halloran, Fisher and Rab	2008	Horticulture Australia Limited (HAL)	Conference Paper	Australia	micro	deterministic	Cucumbers	production - transport	2
0.09	Van Hauwermeiren, A., Coene, G., Engelen, G., & Mathijs, E.	2007	Journal of Environmental Policy and Planning	Report	Belgium	micro	deterministic	Carrot	transport	26

CO_2/ kg	Authors	Year of Publication	Journal	Type of pubblication	Analysis location	Macro/micro approach	Deterministic/ Stochastic	Product Involved	Food chain stages	Number of Citations
0.09	Jones, A.	2002	Environmental Management	Peer review	UK	macro	deterministic	Apple	Transport post production to home and landfill waste (road and sea)	73
0.10	H. Pathak, N. Jain, A. Bhatia, J. Patel, P.K. Aggarwal	2010	Agriculture, Ecosystems and Environment	Peer review	India	micro	deterministic	Banana	production - processing - Transport	4
0.11	Mason, R., Simons, D. Peckham, C., & Wakeman, T	2002	Department of Transport, UK	Report	UK, EU & NZ	macro	deterministic	Apple	transport	7
0.12	Koerber, Jones, Hill, Milà i Canals, Nyeko, York and Jones	2009	Journal of Applied Ecology	Peer review	UK	micro	deterministic	Broccoli	production	7
0.12	O'Halloran, Fisher and Rab	2008	Horticulture Australia Limited (HAL)	Conference Paper	Australia	micro	deterministic	Onion	production - transport	2
0.12	Halberg	2008	Colloque international Agricolture Biologique et changement climatique, International conference Organic agricolture and climate change	Conference Paper	Denmark	micro	deterministic	Carrot	production	8
0.12	O'Halloran, Fisher and Rab	2008	Horticulture Australia Limited (HAL)	Conference Paper	Australia	micro	deterministic	Carrot	production - transport	2
0.13	O'Halloran, Fisher and Rab	2008	Horticulture Australia Limited (HAL)	Conference Paper	Australia	micro	deterministic	Celery	production - transport	2
0.13	Ecoinvent Centre	2007	Swiss Centre	Report	Switzerland	-	stochastic	Potato	production	0
0.13	Röös, Sundberg and Hansson	2010	Int J Life Cycle Assess	Peer review	Sweden	macro	stochastic	Potato	production - transport	11
0.13	Koerber, Jones, Hill, Milà i Canals, Nyeko, York and Jones	2009	Journal of Applied Ecology	Peer review	UK	micro	deterministic	Lettuce	production	7
0.13	H. Pathak, N. Jain, A. Bhatia, J. Patel, P.K. Aggarwal	2010	Agriculture, Ecosystems and Environment	Peer review	India	micro	deterministic	Potato	production - processing - Transport	4
0.13	O'Halloran, Fisher and Rab	2008	Horticulture Australia Limited (HAL)	Conference Paper	Australia	micro	deterministic	Potato	production - transport	2
0.14	H. Pathak, N. Jain, A. Bhatia, J. Patel, P.K. Aggarwal	2010	Agriculture, Ecosystems and Environment	Peer review	India	micro	deterministic	Cauliflower	production - processing - Transport	4

0.14	H. Pathak, N. Jain, A. Bhatia, J. Patel, P.K. Aggarwal	2010	Agriculture, Ecosystems and Environment	Peer review	India	micro	deterministic	Brinjal	production - processing - Transport	4
0.14	Koerber, Jones, Hill, Milà i Canals, Nyeko, York and Jones	2009	Journal of Applied Ecology	Peer review	UK	micro	deterministic	Broccoli	production	7

CO_2/kg	Authors	Year of Publication	Journal	Type of pubblication	Analysis location	Macro/micro approach	Deterministic/ Stochastic	Product Involved	Food chain stages	Number of Citations
0.15	Fogelberg, C. & Carlsson-Kanyama, A.	2006	Swedish Defence Agency (FOI)	Report	Denmark	macro	deterministic	Onion	production - packaging - transport	2
0.16	Fogelberg, C. & Carlsson-Kanyama, A.	2006	Swedish Defence Agency (FOI)	Report	Netherlands	macro	deterministic	Carrot	production - packaging - transport	2
0.17	O'Halloran, Fisher and Rab	2008	Horticulture Australia Limited (HAL)	Conference Paper	Australia	micro	deterministic	Tomato	production - transport	2
0.17	Saunders, C., Barber, A., & Taylor, G.	2006	The Agribusiness and Economics Research Unit (AERU) - Lincoln University	Research Report No. 287	UK	macro	deterministic	Onion	production - packaging - storage	129
0.17	O'Halloran, Fisher and Rab	2008	Horticulture Australia Limited (HAL)	Conference Paper	Australia	micro	deterministic	Melon -Rock and cantaloupe	production - transport	2
0.18	Saunders, C., Barber, A., & Taylor, G.	2006	The Agribusiness and Economics Research Unit (AERU) - Lincoln University	Research Report No. 288	New Zealand	macro	deterministic	Onion	production - packaging - transport	129
0.19	Saunders, C., Barber, A., & Taylor, G.	2006	The Agribusiness and Economics Research Unit (AERU) - Lincoln University	Research Report No. 286	New Zealand	macro	deterministic	Apple	production - transport	129
0.19	A. G. Williams & E. Audsley & D. L. Sandars	2010	Int J Life Cycle Assess	Peer review	UK	micro	stochastic	Potato	production	4
0.20	O'Halloran, Fisher and Rab	2008	Horticulture Australia Limited (HAL)	Conference Paper	Australia	micro	deterministic	Lettuce	production - transport	2
0.20	A. G. Williams & E. Audsley & D. L. Sandars	2010	Int J Life Cycle Assess	Peer review	UK	micro	stochastic	Potato	production	4
0.21	Halberg	2008	Colloque international Agricolture Biologique et changement climatique, International conference Organic agricolture and climate change	Conference Paper	Denmark	micro	deterministic	Carrot	production	8
0.25	A.G. Williams, E. Pell, J Webb, D Evans, E. Moorhouse, P. Watkiss	2007	J Bates, AEA	Report	UK	macro	deterministic	Maincrop potato	production - packaging - transport	5

0.27	Saunders, C., Barber, A., & Taylor, G.	2006	The Agribusiness and Economics Research Unit (AERU) - Lincoln University	Research Report No. 285	UK	macro	deterministic	Apple	production - storage	129
0.27	O'Halloran, Fisher and Rab	2008	Horticulture Australia Limited (HAL)	Conference Paper	Australia	micro	deterministic	Melon – Water	production - transport	2
0.27	Koerber, Jones, Hill, Milà i Canals, Nyeko, York and Jones	2009	Journal of Applied Ecology	Peer review	Spain	micro	deterministic	Broccoli	production	7
0.28	Carlsson-Kanyama	1998	Ambio	Peer review	Sweden	macro	stochastic	Carrot	production, storage, transport	21
CO_2/ kg	**Authors**	**Year of Publication**	**Journal**	**Type of pubblication**	**Analysis location**	**Macro/micro approach**	**Deterministic/ Stochastic**	**Product Involved**	**Food chain stages**	**Number of Citations**
0.28	Jones, A.	2002	Environmental Management	Peer review	USA	macro	deterministic	Apple	Transport post production to home and landfill waste (road and sea)	73
0.29	A.G. Williams, E. Pell, J Webb, D Evans, E. Moorhouse, P. Watkiss	2007	J Bates, AEA	Report	UK	macro	deterministic	Early potato	production - packaging - transport	5
0.30	Foster, C., Green, K., et al.	2006	Manchester Business School, United Kingdom	Report	UK	micro	deterministic	Potato	production - packaging - transport - consumption	95
0.31	Carlsson-Kanyama	1998	Ambio	Peer review	Denmark	macro	stochastic	Carrot	production, storage, transport	21
0.36	H. Pathak, N. Jain, A. Bhatia, J. Patel, P.K. Aggarwal	2010	Agriculture, Ecosystems and Environment	Peer review	India	micro	deterministic	Apple	production - processing - Transport	4
0.38	O'Halloran, Fisher and Rab	2008	Horticulture Australia Limited (HAL)	Conference Paper	Australia	micro	deterministic	Capsicums (excl. chillies)	production - transport	2
0.40	Edwards-Jones,Plassmann, York, Hounsome, Jones, Mila` i Canals	2008	Environmental science & policy	Peer review	UK	macro	stochastic	Lettuce	transport	33
0.40	Edwards-Jones,Plassmann, York, Hounsome, Jones, Mila` i Canals	2008	Environmental science & policy	Peer review	UK	macro	stochastic	Broccoli	transport	33

0.43	Carlsson-Kanyama	1998	Ambio	Peer review	Sweden	macro	stochastic	Tomato	production, storage, transport	21
0.46	O'Halloran, Fisher and Rab	2008	Horticulture Australia Limited (HAL)	Conference Paper	Australia	micro	deterministic	Pumpkins	production - transport	2
0.48	Carlsson-Kanyama	1998	Ambio	Peer review	Netherlands	macro	stochastic	Carrot	production, storage, transport	21
0.48	Carlsson-Kanyama	1998	Ambio	Peer review	Germany	macro	stochastic	Carrot	production, storage, transport	21
0.48	Carlsson-Kanyama	1998	Ambio	Peer review	UK	macro	stochastic	Carrot	production, storage, transport	21
0.48	A.G. Williams, E. Pell, J Webb, D Evans, E. Moorhouse, P. Watkiss	2007	J Bates, AEA	Report	Israel	macro	deterministic	Maincrop potato	production - packaging - transport	5
0.52	A.G. Williams, E. Pell, J Webb, D Evans, E. Moorhouse, P. Watkiss	2007	J Bates, AEA	Report	Israel	macro	deterministic	Early potato	production - packaging - transport	5
CO_2/ kg	**Authors**	**Year of Publication**	**Journal**	**Type of pubblication**	**Analysis location**	**Macro/micro approach**	**Deterministic/ Stochastic**	**Product Involved**	**Food chain stages**	**Number of Citations**
0.52	O'Halloran, Fisher and Rab	2008	Horticulture Australia Limited (HAL)	Conference Paper	Australia	micro	deterministic	Chillies (excl. capsicums)	production - transport	2
0.61	Van Hauwermeiren, A., Coene, G., Engelen, G., & Mathijs, E.	2007	Journal of Environmental Policy and Planning	Report	Belgium	micro	deterministic	Tomato	production - transport	26
0.61	O'Halloran, Fisher and Rab	2008	Horticulture Australia Limited (HAL)	Conference Paper	Australia	micro	deterministic	Cabbages	production - transport	2
0.63	Carlsson-Kanyama	1998	Ambio	Peer review	Italy	macro	stochastic	Carrot	production, storage, transport	21
0.63	A. Smith, P. Watkiss, G. Tweddle, A. McKinnon, M. Browne, A. Hunt, C. Treleven, C. Nash, S. Cross	2005	AEA Technology on behalf of DEFRA (United Kingdom)	Report	Spain	macro	deterministic	Tomato	production - transport - consumption	80
0.74	A.G. Williams, E. Pell, J Webb, D Evans, E. Moorhouse, P. Watkiss	2007	J Bates, AEA	Report	Spain	macro	deterministic	Tomato	production - packaging - transport	5
0.81	Carlsson-Kanyama	1998	Ambio	Peer review	Spain	macro	stochastic	Tomato	production, storage,	21

									transport	
0.85	O'Halloran, Fisher and Rab	2008	Horticulture Australia Limited (HAL)	Conference Paper	Australia	micro	deterministic	Zucchini and button squash	production - transport	2
0.90	A.G. Williams, E. Pell, J Webb, D Evans, E. Moorhouse, P. Watkiss	2007	J Bates, AEA	Report	Spain	macro	deterministic	Strawberries	production - packaging - transport	5
0.99	A.G. Williams, E. Pell, J Webb, D Evans, E. Moorhouse, P. Watkiss	2007	J Bates, AEA	Report	UK	macro	deterministic	Strawberries	production - packaging - transport	5
1.04	A.G. Williams, E. Pell, J Webb, D Evans, E. Moorhouse, P. Watkiss	2007	J Bates, AEA	Report	Spain	macro	deterministic	Tomato	production - packaging - transport	5
1.06	Van Hauwermeiren, A., Coene, G., Engelen, G., & Mathijs, E.	2007	Journal of Environmental Policy and Planning	Report	Belgium	micro	deterministic	Tomato	production - transport	26
1.19	O'Halloran, Fisher and Rab	2008	Horticulture Australia Limited (HAL)	Conference Paper	Australia	micro	deterministic	Broccoli	production - transport	2
1.35	Van Hauwermeiren, A., Coene, G., Engelen, G., & Mathijs, E.	2007	Journal of Environmental Policy and Planning	Report	Belgium	micro	deterministic	Lettuce	production - transport	26
1.71	Van Hauwermeiren, A., Coene, G., Engelen, G., & Mathijs, E.	2007	Journal of Environmental Policy and Planning	Report	Belgio	micro	deterministic	Tomato	production - transport	26
2.20	O'Halloran, Fisher and Rab	2008	Horticulture Australia Limited (HAL)	Conference Paper	Australia	micro	deterministic	Asparagus	production - transport	2
2.24	A.G. Williams, E. Pell, J Webb, D Evans, E. Moorhouse, P. Watkiss	2007	J Bates, AEA	Report	UK	macro	deterministic	Tomato	production - packaging - transport	5
CO_2/ kg	**Authors**	**Year of Publication**	**Journal**	**Type of pubblication**	**Analysis location**	**Macro/micro approach**	**Deterministic/ Stochastic**	**Product Involved**	**Food chain stages**	**Number of Citations**
2.28	O'Halloran, Fisher and Rab	2008	Horticulture Australia Limited (HAL)	Conference Paper	Australia	micro	deterministic	Cauliflower	production - transport	2
2.35	Van Hauwermeiren, A., Coene, G., Engelen, G., & Mathijs, E.	2007	Journal of Environmental Policy and Planning	Report	Belgium	micro	deterministic	Tomato	production - transport	26
2.39	A. Smith, P. Watkiss, G. Tweddle, A. McKinnon, M. Browne, A. Hunt, C. Treleven, C. Nash, S. Cross	2005	AEA Technology on behalf of DEFRA (United Kingdom)	Report	UK	macro	deterministic	Tomato	production - transport - consumption	80
3.11	A.G. Williams, E. Pell, J Webb, D Evans, E. Moorhouse, P. Watkiss	2007	J Bates, AEA	Report	Spain	macro	deterministic	Tomato	production - packaging - transport	5

4.10	Carlsson-Kanyama	1998	Ambio	Peer review	Netherlands	macro	stochastic	Tomato	production, storage, transport	21
4.20	Carlsson-Kanyama	1998	Ambio	Peer review	Sweden	macro	stochastic	Tomato	production, storage, transport	21
5.12	A.G. Williams, E. Pell, J Webb, D Evans, E. Moorhouse, P. Watkiss	2007	J Bates, AEA	Report	UK	macro	deterministic	Tomato	production - packaging - transport	5
5.60	Carlsson-Kanyama	1998	Ambio	Peer review	Denmark	macro	stochastic	Tomato	production, storage, transport	21
5.86	A.G. Williams, E. Pell, J Webb, D Evans, E. Moorhouse, P. Watkiss	2007	J Bates, AEA	Report	UK	macro	deterministic	Tomato	production - packaging - transport	5
9.28	Van Hauwermeiren, A., Coene, G., Engelen, G., & Mathijs, E.	2007	Journal of Environmental Policy and Planning	Report	Belgium	micro	deterministic	Tomato	production - transport	26
9.29	Van Hauwermeiren, A., Coene, G., Engelen, G., & Mathijs, E.	2007	Journal of Environmental Policy and Planning	Report	Belgium	micro	deterministic	Tomato	production - transport	26

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