Environmental assessment of Catalan fruit production focused on carbon and water footprint

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A thesis submitted in fulfilment of the requirements for the PhD degree in Environmental Sciences and Technology

Bellaterra, June of 2016

The present thesis entitled Environmental assessment of fruit production focused on Carbon and water footprint by Elisabet Vinyes i Guix has been carried out at the Institute of Environmental Science and Technology (ICTA) at Universitat Autònoma de Barcelona (UAB).

Elisabet Vinyes i Guix

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Pere Muñoz   Carles M. Gasol   Luis Asin

Bllaterra (Cerdanyola del Vallès), June of 2016.

“Now we finally have realized the terrible damage
we have caused to the environment, we are
exaggerating our ingenuity to find technological
solutions. The technology alone is not enough. We
also have to put the heart into it.”

Jane Goodall

TABLE OF CONTENTS

ACKNOWLEDGMENTS

First and foremost I would like to thank my supervisors who gave me the opportunity to develop this thesis: Carles, Pere and Luis, thank you for the trust you have placed in me always, the patience you've had, the challenges proposed and your kindly dedication. I would like to thank Xavier Gabarrell, for give me the opportunity to compose my thesis in Sostenipra Research group.

I would also like to thank Inèdit Innovació organization for giving me the opportunity to start with environmental research and for sharing their knowledge and resources to develop this work. As well I want to thank you to IRTA organization for the data and information that it they provided us which had been essential to develop this work

Thanks to all the colleagues of the research group Sostenipra: Esther, Violeta, Anna, David, Pere, Júlia, Jesús, who help and inspirited me to carry out this work, thank you for your kindly advices, social events and seminars, and specially for sharing your information and experience.

Furthermore thank you to my UAB Master colleagues (now PhD): Esther, Violeta and David, who inspired me and gives me the courage to continue my environmental background and start the PhD studies.

Above all, I would like to thank all my friends and family for encourage me and listening tirelessly the endless times I have spoken about my thesis and environmental issues. Also thank you to all those who in their own way have contributed directly or indirectly to the development of this thesis.

Gràcies pel teu support incondicional i per ensenyar-me a córrer com una formigueta per arribar a la meta.

SUMMARY

During the last decade, the agricultural sector has changed from traditional practices to more intensive methods in order to increase their productivity, as a response to the growing demand of an increasing population. Consequently food production has become an important contribution to the depletion of natural resources and climate change.

To develop a proper environmental management it is essential for industries to know the main environmental indicators of their products and production processes: emissions, energy and water consumption, waste generation, efficiency, etc. It also can help producers to improve their production system management, give an added environmental value to their product, and provide more information to consumers.

Considering that apple and peach are two significant fruits in the Mediterranean countries, and most publications on environmental impacts of fruit productions are based on one single productive year, this study attempts to perform an environmental analysis of apple and peach production using Life Cycle Assessment (LCA) approach, in order to provide new environmental information of fruit, and also introduce a multiyear perspective analysis to identify the variability of the environmental impacts related to annual orchard yield, geographic and climatic conditions. The results will be expressed in terms of Carbon footprint (CF) and Water Footprint (WF) terms, In order to compare these concepts from a methodological point of view, and how those can be introduced to inform fruit sector and the consumers. The CF measures the emissions of CO_{2eq} related with the life cycle of a product or services in terms of Global warming. WF measures the water consumed to develop a product a good or a service in terms of litres.

This study follows an interdisciplinary framework, considering the following stages in the process of fruit production: agricultural stages, retail, consumption ad disposal, as well as the back-ground system related with materials and substances production. The systems studied are apple and peach orchards located in Catalonia. Data used have been collected directly from an orchard of the Environmental Horticulture Unit at the Institute of Agriculture and Food Research and Technology (IRTA) located in the North East of Spain, and covers between 9-15 years of real production.

This dissertation contributes to detect the hot spots of the environmental impact related to fruit production with a perspective of LCA, as well as evaluate the advantages and weakness the existing methodologies to calculate the Carbon and water Footprints, besides developing methodological aspects and generating new data on the topic and fruit producers and all the actors involved in fruit production. Although the study demonstrates that LCA is a useful tool for estimating the impact associated with a product or process and calculate the CF and WF indicators, there are still some issues to be resolved regarding to the quality of environmental impact databases and data available because sometimes, it is needed to work with generic data, and it can generate variability in the results.

RESUMEN

Durante la última década, el sector agrícola ha pasado de las prácticas tradicionales a métodos más intensivos con el fin de aumentar su productividad, como respuesta a la creciente demanda de una población creciente. En consecuencia la producción de alimentos ha generado una importante contribución al agotamiento de los recursos naturales y el cambio climático. Para desarrollar una gestión ambiental adecuada es esencial para las industrias conocer los principales indicadores ambientales de sus productos y procesos: emisiones, consumo de energía y agua, generación de residuos, eficiencia, etc. Conocer esta información puede ayudar a los productores a mejorar la gestión de sus sistemas productivos, dar un valor ambiental añadido a sus productos, y también proporcionar más información a los consumidores.

Teniendo en cuenta que la manzana y melocotón son dos frutas significativas en los países mediterráneos, y la mayoría de las publicaciones sobre los impactos ambientales de la produccion de fruta se basan en un año productivo único, este estudio pretende realizar un análisis ambiental de la producción de manzana y melocotón utilizando la metodología del Análisis de Ciclo de Vida (ACV), con el fin de proporcionar nueva información ambiental sobre la fruta, y también introducir un análisis de la perspectiva plurianual para identificar la variabilidad de los impactos ambientales relacionados con el rendimiento anual de las plantaciones, las condiciones geográficas y climáticas. Los resultados se expresarán en términos de huella de carbono y de agua, con el fin de comparar estos conceptos desde un punto de vista metodológico, y que para que la información pueda servir para informar sector de la fruta y de los consumidores. La huella de carbono cuantifica las emisiones de CO_2 equivalentes relacionadas con el ciclo de vida de un producto o servicio en términos de calentamiento global. La huella hídrica cuantifica el agua que se consume para desarrollar un producto de un bien o un servicio.

Este estudio sigue un marco interdisciplinario, teniendo en cuenta las siguientes etapas en el proceso de producción de la fruta: fase agrícola, distribución, consumo, residuos, así como el sistema relacionado con los materiales y sustancias relacionados con la producción de fruta. Los sistemas estudiados son huertos de manzano y melocotón situados en Cataluña. Los datos utilizados han sido recogidos directamente de un huerto de la Unidad de Horticultura Ambiental en el Instituto de Investigación para la Agricultura y la Alimentación y Tecnología (IRTA), ubicado en la provincia de Lleida en el noreste de España, el estudio abarca entre 9-15 años de producción real. Esta tesis contribuye a detectar los puntos críticos del impacto ambiental relacionados con la producción de fruta con una perspectiva de ACV, así como evaluar las ventajas y debilidades de las metodologías existentes para calcular la huella de carbono y huella de agua, además de desarrollar nuevos aspectos metodológicos y la generación de nuevos datos sobre el tema para los productores de frutas y otros actores involucrados en ciclo de producción de fruta. Aunque el estudio demuestra que el ACV es una herramienta útil para estimar el impacto asociado a un producto o proceso y para el cálculo de los indicadores huella de carbono i huella hídrica, existen todavía algunas cuestiones por resolver en cuanto a la calidad de las bases de datos de impacto ambiental y los datos disponibles, porque a veces, es necesario trabajar con datos genéricos.

RESUM

Durant l'última dècada, el sector agrícola ha passat de les pràctiques tradicionals a mètodes més intensius per tal d'augmentar la seva productivitat, com a resposta a la creixent demanda d'una població creixent. En conseqüència la producció d'aliments ha desencadenat una important contribució a l'esgotament dels recursos naturals i l'impacte ambiental. Per desenvolupar una gestió ambiental adequada, és essencial per a les indústries de conèixer els principals indicadors ambientals dels seus productes i processos: emissions, consum d'energia i consum d'aigua, generació de residus, eficiència, etc. Tot això pot ajudar als productors a millorar la gestió dels seus sistemes productius, donar un valor ambiental afegit al seu producte, i proporcionar més informació ambiental als consumidors.

Tenint en compte que la poma i préssec són dues fruites significatives en els països mediterranis, i que la majoria de les publicacions sobre els impactes ambientals de la producció de fruita es basen en un únic any productiu, aquest estudi intenta realitzar un anàlisi ambiental de la producció de poma i préssec utilitzant amb un enfocament d'Anàlisi del Cicle de Vida (ACV), amb la finalitat de proporcionar nova informació ambiental sobre la fruita, i també introduir una anàlisi des de la perspectiva plurianual per tal d'identificar la variabilitat dels impactes ambientals relacionats amb el rendiment anual d'una plantació, les condicions geogràfiques i climàtiques. Els resultats s'expressen en termes de petjada de carboni i petjada hídrica, per tal de comparar aquests conceptes des d'un punt de vista metodològic, i també informar al sector de les fruita i dels consumidors. La petjada de carboni, quantifica les emissions CO_2 equivalents relacionades amb el cicle de vida d'un producte o servei en termes d'escalfament global. La petjada hídrica mesura l'aigua que es consumeix per desenvolupar un producte d'un bé o un servei.

Aquest estudi segueix un marc interdisciplinari, tenint en compte les següents etapes en el procés de producció de la fruita: fase agrícola, comercialització, distribució, el consum i disposició final, així com l'obtenció dels materials i substàncies relacionats amb la producció de fruita. Els sistemes estudiats són horts de poma i préssec situats a Catalunya. Les dades utilitzades han estat recollides directament dels horts de la Unitat d'Horticultura Ambiental de l'Institut de Recerca per a l'Agricultura i l'Alimentació i Tecnologia (IRTA), ubicat a la província de Lleida, i abarca entre 9-15 anys de producció real. Aquesta tesi contribueix a detectar els punts crítics de l'impacte ambiental relacionat amb la producció de fruita des d'una perspectiva d'anàlisi del cicle de vida, així com avaluar les metodologies existents per calcular la petjada de carboni i d'aigua, a més de desenvolupar nous aspectes metodològics, i generar noves dades sobre el tema, que seran útils pels productors de fruita i també pels altres actors involucrats en la producció de fruita. Encara que l'estudi demostra que l'ACV és una eina útil per estimar l'impacte associat a un producte o un procés, i també pel càlcul de la petjada de carboni i la petjada hídrica, encara hi ha algunes qüestions per resoldre pel que fa la qualitat de les dades i base de dades disponibles per quantificar l'impacte ambiental, ja que a vegades és necessari treballar amb dades genèriques, que poden generar variabilitat en els resultats.

LIST OF ACRONYMS AND ABBREVIATIONS

ACV	Anàlisi Cicle de Vida
ALO	Agricultural land occupation
BSI	British Standards Institute
CCH	Climate change
CED	Cumulative energy demand
CF	Carbon Footprint
CO_2	Carbon dioxide
$CO_{2\ eq.}$	Carbon dioxide equivalent emissions
DARP	Catalan Department of Agriculture Fisheries and Livestock
Etox	Ecotoxcity
FAO	Food and Agriculture Organization of the United Nations
FDP	Fossil depletion
FEU	Freshwater eutrophication
FU	Functional Unit
GDP	Gross domestic product
GHG	Greenhouse gas emissions
GW	Global warming
GWP	Global warming potential
HDPE	High density polyethylene HTP
ha	Hectare
HTP	Human toxicity potential
ICTA	Institute of Environmental Science and Technology (UAB)
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return):
IRTA	Institute of Agriculture and Food Research and Technology
ISO	International Organization for Standardization
Kg	Kilogram
kw	Kilo watt
l	Litre
LCA	Life Cycle Assessment
LCC	Life Cycle costing
LCI	Life Cycle Inventory

LCIA	Life Cycle Impact Assessment
LDPE	Light density polyethylene
MAGRAMA	Spanish Ministry of Environment, and Rural and Marine
MJ	Mega joules
m^3	Cubic meter
m^2	Squared meter
MDP	Metal depletion
MEU	Marine eutrophication
NLT	Natural land transformation
NPV	Net Present Value
NRE	Demand for non-renewable energy resources
ODP	Ozone depletion
PAS	Publicly Available Specification
PCR	Product Category Rules
PHO	Photochemical oxidant formation
PP	Polypropylene
PVC	Polyvinyl chloride
RE	Demand for renewable energy resources
SD	Standard deviation
SETAC	Society of Environmental Toxicology and Chemistry
SOSTENIPRA	Sostenipra Sustainability and Environmental Prevention research group TA
t	Tonne
tkm	Tonne per kilometer
TAC	Terrestrial acidification
UAB	Universitat Autònoma de Barcelona
ULO	Urban land occupation
UNEP	United Nations Environmental Program
WDP	Water depletion
WF	Water footprint

LIST OF FIGURES

LIST OF TABLES

PREFACE

The present doctoral thesis was developed within the research group on Sustainability and Environmental Prevention (Sostenipra) at the Institute of Environmental Science and Technology (ICTA) of the Universitat Autònoma de Barcelona (UAB) from October 2013 to February 2016, in accordance with Inèdit Innovació SL organization and the Environmental Horticulture Unit at the Institute of Agriculture and Food Research and Technology (IRTA).

This dissertation perform an environmental analysis of apple and peach production using Life Cycle Assessment (LCA), in order to provide new information on fruit, and also introduce a multiyear perspective analysis to identify the variability of the environmental impacts related to annual orchard yield, geographic and climatic conditions. It also aims to provide water management strategies in order to optimize water use efficiency in agriculture. The results will be expressed in terms of Carbon footprint (CF) and water Footprint (WF) perspectives.

The novelty of the dissertation not only relies on the topic of environmental impact of fruit production, also on the introduction of multiyear approach, use of regional data to consider the variation of the results depending the geographic localization and climate conditions.

The dissertation is mainly based on the following papers and chapters either published or under review in peer-reviewed indexed journals:

Vinyes, E., C.M. Gasol, L. Asin, S. Alegre, and P. Muñoz. 2015. Life Cycle Assessment of multiyear peach production. *Journal of Cleaner Production*.
http://linkinghub.elsevier.com/retrieve/pii/S0959652615005880.

Vinyes, E., L. Asin, S., P. Muñoz, S. Alegre, J. Boschmonart and C.M. Gasol. 2016. Life Cycle Assessment of apple and peach production, distribution and consumption, in Mediterranean fruit sector. *Submitted in April 2016 to Journal of Cleaner Production, under revision.*

Vinyes, E., P. Muñoz, L. Asin, S. Alegre, and C.M. Gasol. 2016. Water Footprint of Mediterranean Fruit Production: A Case Study of Spanish Apple and Peach. *Submitted in May 2016 to Journal of Industrial Ecology.*

Vinyes, E., C.M. Gasol, L. Asin, S. Alegre, and P. Muñoz. 2016. Calculation of Carbon footprint of different apple cultivation systems: Central axis and Fruiting wall. *Submitted in June 2016 to Journal of Industrial Ecology.*

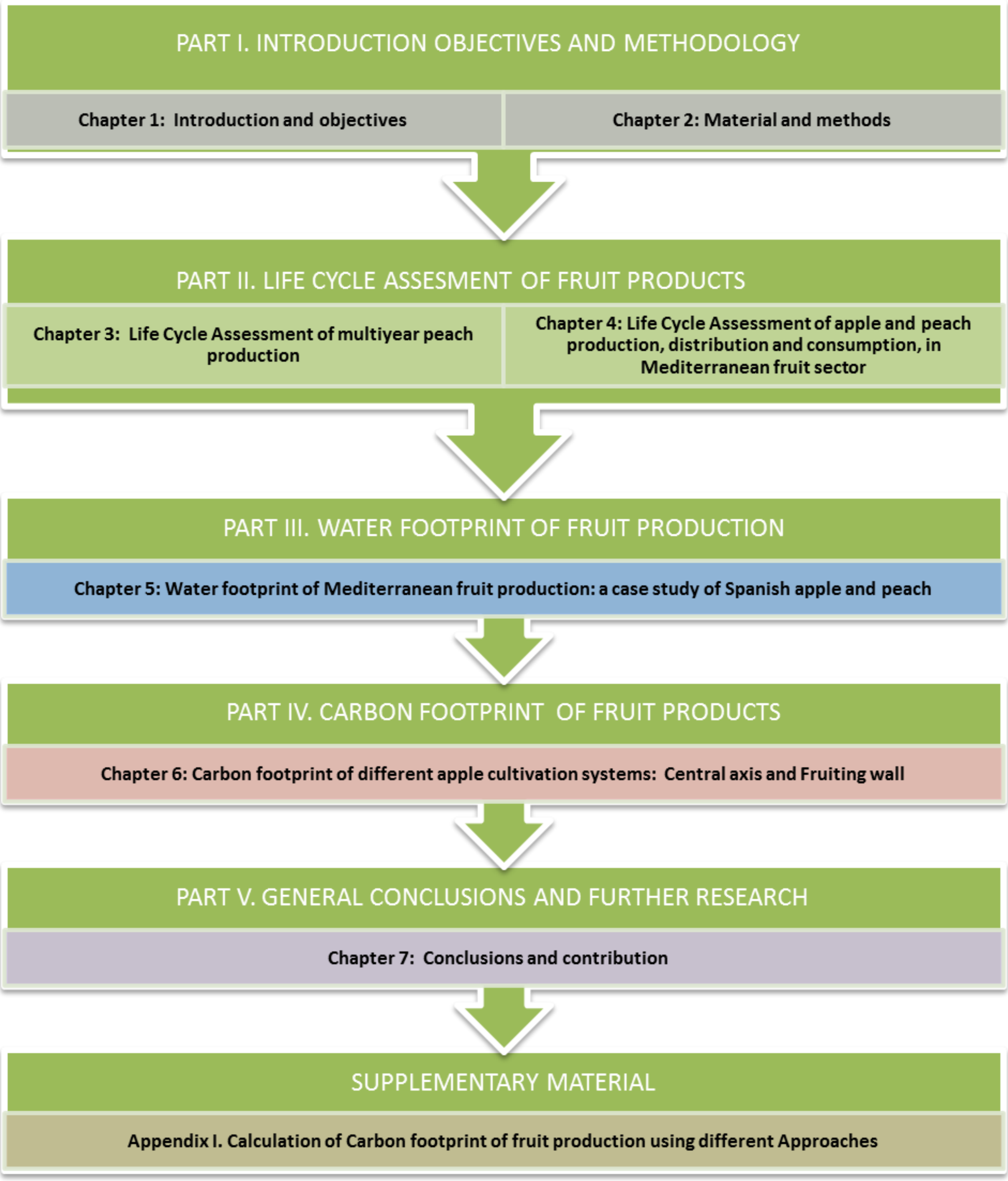
The following oral communications and posters presented to congresses and conferences also form part of this doctoral thesis:

Poster: SETAC EUROPE 18th LCA Case Study Symposium. Sustainability Assessment. Copenhagen, Denmark, 26-28 November 2012. Carbon footprint and water footprint of Catalan fruit sector. Vinyes Elisabet, Gasol Carles M., Asin Luis, Muñoz Pere

Poster LCM 2015. Copenhagen. August 2015. Calculation of Carbon footprint for different apple cultivation systems. Vinyes Elisabet, Gasol Carles M., Asin Luis, Alegre Simó, Muñoz Pere

STRUCTURE OF THE DISSERTATION

The structure of this dissertation this thesis is organised into five main parts and seven chapters, as follows:



PART I. INTRODUCTION OBJECTIVES AND METHODOLOGY

Chapter 1: Introduction and objectives

Chapter 2: Material and methods

PART II. LIFE CYCLE ASSESMENT OF FRUIT PRODUCTS

Chapter 3: Life Cycle Assessment of multiyear peach production

Chapter 4: Life Cycle Assessment of apple and peach production, distribution and consumption, in Mediterranean fruit sector

PART III. WATER FOOTPRINT OF FRUIT PRODUCTION

Chapter 5: Water footprint of Mediterranean fruit production: a case study of Spanish apple and peach

PART IV. CARBON FOOTPRINT OF FRUIT PRODUCTS

Chapter 6: Carbon footprint of different apple cultivation systems: Central axis and Fruiting wall

PART V. GENERAL CONCLUSIONS AND FURTHER RESEARCH

Chapter 7: Conclusions and contribution

SUPPLEMENTARY MATERIAL

Appendix I. Calculation of Carbon footprint of fruit production using different Approaches

PART I

Introduction objectives and methodology

Chapter 1

Photography by Elisabet Vinyes

Introduction and objectives

Chapter 1: Introduction and objectives.

This chapter provides the reader with the purpose of the thesis and the context that it has been developed, as well as and introducing the background of agricultural production, especially regarding fruit production, and the environmental impact related. This chapter also describes the motivations and objectives of this dissertation.

1.1. Current situation of fruit production

Production and consumption of agricultural products have different geographical distribution. The climate, geography and economy of a nation influence the level of agricultural production of a country. This makes that the production of some products is very low in some countries while others are large producers.

Fruit production has risen in importance in agricultural sector in the last two decades, for increasing the productivity and competitiveness around the world. Almost 640 million tonnes of fruit and more than 1 billion tons of vegetables were gathered throughout the world (FAO, 2011).

1.1.1. Global fruit production

Apple is one of the most widely cultivated fruit crops and is produced commercially in over 80 countries around the world (FAO, 2011). Its production is the third highest fruit crop in the world after banana and grape. Most types of apples are grown in temperate zones because of the high chilling requirements for proper bud break in the spring. Production areas have increased significantly in recent decades until 2000, when China took the lead in production.

According to FAO data base (2011) total production of apples stabilized during 2000-2010 at 60 to 70 million t/year. In 2009, the harvested area exceeded 4.9 million ha with an average yield of 14.7 t/ha. China is the largest apple-producing country (42% of world production) and its production is six-fold larger than the second country (United States, 7%).

Peach production is limited worldwide by its narrow range of climatic adaptation. The fruit is usually consumed fresh, so peach is grown mostly under irrigation even in many sub-humid areas to guarantee its quality. According to FAO data base (2011) there were over 1.5 million ha of peach and nectarine globally with an average yield of 13.0 t/ha. The main producing country is China, which represents 50% of the world peach production. Production in China during the last decades reached over from 380,000 tonnes. China's average yield in 2009 was over 10 million tonne, followed by Italy. Other major commercial production areas are located in southern Europe (Spain, Greece, and France), United States, Chile, and Australia. Even so highest yields are obtained in United States with almost 20 t/ha.

The world Mediterranean area is very rich in terms of agricultural production, especially regarding fruit production. Peach and apple are two significant products in the Mediterranean fruit sector. According FAOSTAT statistics (2015), Spain is the second peach and apple producer in the European Union.

1.1.2. Spanish fruit production

In Spain, the agriculture is one of the main contributors to the national economy. The main crops cultivated in Spain are olives, barley, wheat, sugar beet, corn, potatoes, rye, oats, rice, tomatoes and onion. Spain also has extensive vineyards and citrus orchards and olive groves. Climatic and topographical conditions make rained agriculture predominates in considerable parts of the country. The fruit sector is one of the most important sectors of the Spanish economy; It encompasses a wide range of products, which makes it to be present in most of the country, both direct and indirect jobs, and is represented by multiple structures of production and marketing.

The area used in Spain to cultivate fruit and vegetables as is about 1,571,000 hectares (average years 2008-2010); of which 650,000 hectares are shell fruit. Of the remaining 921,000 hectares corresponds to 38% vegetables, 34% to citrus and 28% non-citrus fruit trees, 75,000 hectares of potato. The general development of land is low in vegetables and potato, but stability in fruits and nuts (MAGRAMA 2015).

According to MAGRAMA data (2015) Spain is the leading exporter of fruit and vegetables from the European Union and one of the top three world exporters with China and the US. The fruit sector has a clear export vocation and that 47% of production (average years from 2008 to 2012) is exported, and is the first subsector within the total exports of the food industry. Exports have a growing trend in recent years in both volume and value, having reached in 2012 a record 12.1 million tons and 10,829 million euros in value. The main products exported are greenhouse vegetables (tomato, pepper, cucumber), citrus and peach and nectarine. Imports are less significant and also in recent years are following a downward trend. The main products imported are bananas, pineapple, apple and kiwi.

The provinces along the Mediterranean coast have irrigation systems for some time, and this coastal belt that previously was barren has become one of the most productive areas of Spain, where it is common to find crops under greenhouse facilities. In the Ebro valley because of the proximity to the river basin it can be founded irrigation projects where fruit (apple and peach trees) predominate. Small irrigated orchards are extended by more humid areas as and Valencia where the orchards citrus predominate.

1.1.3. Catalan fruit production

The Catalan food industry is one of the most important industrial sectors of the Spanish country, contributing 23% of total net turnover in Spain ahead of the chemical industry (MAGRAMA 2015). Catalonia is the Region of the Spain with the highest apple production with a production this means 54% of the total Spanish apple production and 46% of the total cultivated area (MAGRAMA 2014).

To understand the importance of this sector can be noted that the Catalan peach sales abroad account for 41% of total Spanish exports of the product; and apples 62% (Catalan Deparment of Agriculture Fisheries and Livestock; 2014). Catalonia ranks fourth in the context of the European Union in peach, nectarine and pear in, and the seventh in apple (MAGRAMA 2015). So, all of these configure Catalonia as a true power fruit in European scale, in terms of foreign trade and in relation to the scale production.

Table 1.1 Apple and peach production data in Cataloniashows the cultivated area and the tonnes of fruit produced in Catalonia for apple and Peach, distributed among the provinces. As it can be observed in Table 1.1 Apple and peach production data in CataloniaLleida is the region of the Catalonia with the highest cultivated area for apple and peach production (7,694 ha for apple and 8,541 for peach), it means almost 75% of total fruit cultivated area for each fruit.

Table 1.1 Apple and peach production data in Catalonia

	Fruit production					
	Apple	**Peach**	**Apple**		**Peach**	
Units	*ha*	*ha*	*t*	*%*	*t*	*%*
BARCELONA	62	587	1,500	0.5%	6,600	3.0%
GIRONA	2,537	239	100,000	34.1%	2,500	1.1%
LLEIDA	7,694	8,541	190,000	64.9%	186,700	84.2%
TARRAGONA	63	2,068	1,450	0.5%	25,952	11.7%
TOTAL	**10,356**	**11,435**	**292,950**		**221,752**	

(Source MAGRAMA, 2015)

Regarding to the quantities produced, again Lleida is the area where with the highest production for both fruits 190,000t for apple and 186,700t for peach), it means a 65% of total Catalan apple production and 84% of total Catalan peach production. According to (DARP 2014) data of the total tonnes of fruit produced in Catalonia, 90% of peach is consumed as a fresh fruit, and 10% goes to agrifood transformation processes to produce juices or jams. For apple 86% is consumed as fresh product while 14% goes to agrifood transformation processes.

Concerning to total the area cultivated, according to (DARP 2014) data for peach orchards it is accounted that 98% are irrigated orchards and 2% are without irrigation systems. For apple orchards 99% have irrigated systems and 1% is not irrigated. In Catalonia historically predominated orchards with, sprinkle irrigation systems, but due to the low efficiency of these systems it has been gradually changing towards more efficient irrigation systems such as dropping.

1.2. Apple and Peach cultivation operations

Peach and Apple are two important fruits in Mediterranean area. These two fruits are adapted to areas located between 30 and 40 degrees latitude (IRTA 2013). They need to be planted in temperate zones as they have a poor response to low temperatures and frost. Nevertheless, they require cold winter (between 400 and 800 hours of cold). However, genetic improvement has enabled significant progress in recent decades with the production of varieties that can be grown in areas with few hours cold. Moreover, both need abundant light because the fruit is quality, although the trunk and branches are sensitive to sunburn, by the fact that pruning is recommended.

1.2.1. Plantation

In both cases, fruit planting can be done by seed or rootstock. Planting by seeds is used only for hybrids obtained by crossing different varieties in breeding programs. The plantation by rootstocks is used for vegetative propagation of commercial varieties. The best time for planting is conducted in autumn before the winter cold, except in areas where heavy frost planting will be delayed until late winter.

1.2.2. Irrigation

For fruit trees, water providing should be constantly before harvest and increase it moderately just before harvest. The fruits achieve the best taste if they are watered throughout the season. On dry lands, irrigation provides not only increased production but increases quality. One hectare consumed during the growing season of 2,500 to 6,000 cubic meters of water, depending on the time of harvest of the variety. The depth of the field which affect irrigation is about 80 centimetres (IRTA 2010).

Regarding the type of irrigation there are different types of irrigation: drip, sprinkle, furrows and flow. The drip is the most extended and system. In this system the distribution pipes are placed approximately 80 and 120 centimetres. The amount of water can vary between 1 and 10 lifters per hour. Normally it uses from 1 to 1.5 atmospheres of pressure with a flow rate of 2 to 3 litres per hour. The irrigation sprinkler can adapt to different terrain and minimizes the effects of high temperatures but increases the incidence of fungal diseases (Marfà et al. 2000). On the other hand, the traditional irrigation systems furrows and flow are not larger recommended because they require high water volumes ranging between 10,000 and 12,000 cubic metre fruit per hectare (ICTA, 2012).

1.2.3. Fertilization

Fruit trees have a great need for nutrients. They can be applied using fertilizer dosage high in nitrogen, phosphorus and potassium in regularly way and extra farmyard manure in the fall, after the harvest. Almost never, fruit trees are fertilized in the flowering period because they have less nutritional requirements and the amounts of nutrients in the ground often enough.

Foliar analysis should be performed to assess the evolution of macronutrients and micronutrients. In addition to nitrogen dosage, trees often need calcium and manganese, and zinc and a little less manganese dosage. Fertilizers application can be done by tractors and agricultural machinery with specific accessories or through the irrigation system, known as fertirrigation.

1.2.4. Pruning and thinning

Pruning and thinning are essential tasks in the formation of fruit trees in order to influence their calibre and precocity. If this task is not performed, fruit quality will be compromised and the tree will reduce production next year. The best time to perform thinning is one month after the full flowering, when the fruits fall unfertilized and before tightening the bone. An early thinning increases fruit calibre, while a little later is effective. The thinning can be done manually or by chemical agents. For pruning it is recommended to be performed during the period of dormancy, when the tree is leafless, from December to February in pome fruit trees and in March in the bone fruits.

1.2.5. Harvest

Harvest date depends on type of fruit and the target market (local or export market), but in any case recommended values than 6 kg of firmness and sugar content of less than 11o Brix to start harvesting. In Catalonia peach harvest is usually between June and August and the apple harvest between August and September. The harvest of fruits, peach and apple normally are performed manual. In the upper parts of the trees, it is needed manual scales or motorized lift with mobile platforms. The fruits collected will be placed in wooden boxes and will be transported with a tractor trailer to the central fruit building, where later it will be selected according to their characteristics and stored to be distributed later.

1.2.6. Post-harvest, sorting and packaging

Once in the building of the fruit central, fruits will be separated and selected based on their weight, size, colour and appearance, and will be classified into different categories according to the requirements of the target markets (local, international, supermarket or cooperative). Fruits that present wounds, marks or defects usually develop into companies that produce fruit juice. The fruit will be stored in refrigerator chambers in order to keep them in the best conditions to be distributed the following days. Peach pieces only can be conserved for a short period of time, while apple pieces cab be stored for 10-12 month (Milà i Canals et al. 2006).

There are many features that affect apple fruit quality for the fresh market. External features such as size, colour, shape and appearance are very important. For some markets, fruit pieces that has smaller diameter than 65-70 mm have a price penalty. Skin blemishes such as sunburn, rusting and other markings negatively affect fresh quality. So, the fruit appearance has an important role in fresh market value.

Packaging also depends on the requirements of customers and the target market. The contents of each package must be uniform, comprising only for fruit of the same origin, variety, commercial category, maturity and calibre. The fruits must be properly protected. The materials used inside the packaging, especially paper must be new, clean and made of materials that will not cause internal or external alterations to the fruit. The materials that tend to dominate the packaging are: cardboard and wooden for boxes, polypropylene and polystyrene for trays and protective film.

1.3. Agriculture and Environmental problems

Agriculture is a strategic and necessary human activity for any civilization that has been developing for many centuries. Until the mid-twentieth century, agricultural production was practiced in a natural way, using natural techniques and natural inputs.

The globalization of the economy has generated big competence in all productive activities. It represents an important incentive for European countries to try to increase the productivity and international competitiveness of their agricultural and livestock production, in line with an economic growth model based on the quest for short-term profits. This creates an antagonism between commercial and capitalist agriculture carried by intensive farmers and local and traditional farmers.

The intensification of production has led to the degradation of ecosystems and serious ecological imbalances that accentuate acute environmental problems inherited from industrialization. Agricultural production models developed in recent decades have been based on the use of pesticides, synthetic fertilizers and in general all kinds of resources without any control. The main objective of this agricultural model is producing enough food for the population. In fact, in almost all developed countries food is produced in excess of the demand quantities, however, in many cases this type of farming has led to a situation of over-exploitation of land, pollution of ground and surface water and the presence of excessive residues in food.

In recent years, some aspects of intensive agriculture on an industrial scale are increasingly controversial. The growing influence of large companies producing seeds and chemicals and food processing increasingly concerned both farmers and the general public. The disastrous effect on the environment of intensive agriculture has caused vast previously fertile areas have ceased to be so completely and a big impact on the environment.

According to some publications, food production has an important contribution to the depletion of natural resources and generating and important environmental impact, and it contributes intensively to the existential threat of climate change. The IPCC 2007 report estimates that the direct impact of agriculture is about 10–12% of the global anthropogenic greenhouse gases emissions. Barrett (2007) reports that, fruit production is considered an agricultural sector with lower contribution to environmental impacts compared to other crops sectors. A part of the impacts related to climate change, we must consider other direct and indirect environmental impacts related to agricultural production as: energy demand, water and resources consumption, efficiency, waste generation, transformation and land occupation, toxicity impacts, etc.

1.4. Environmental assessment in agricultural products

Despite technological advances and innovations, agriculture is still subject to the soil, environmental and climatic conditions for development. In the international context, to meet the demands of the global market some importing countries of fruit and vegetables have required compliance with certain guidelines aimed at achieving meet the requirements of food and environmental safety, to ensure customer satisfaction and safety consumer.

Therefore the evidence of excessive consumption of resources by intensive agriculture has done several world organizations and some countries began to study the extent of this environmental impact and start demanding environmental measures and good agricultural practices. Consequently environmental tools available can help food producers to detect and to quantify the environmental impact of their products and production processes.

The main environmental impacts related to agricultural activities that currently are under study can be grouped in the following types (ISO14044 2010):

- Energy and resources consumption.
- Climate change.
- Pollution.
- Resource depletion.
- Water pollution and depletion (nitrates, pesticides, etc.).
- Water consumption.
- Toxicity impacts (chemical products use).
- Decrease in soil quality (soil degradation, pollution, erosion, etc.).
- Decrease of biodiversity in cultivated land.
- Land occupation.
- Land conversion.
- Soil erosion and degradation.
- Habitat loss.
- Waste generation.

To develop a correct environmental management, and also to improve their production systems, it is important that agricultural companies identify direct and indirect environmental impacts of their production such as: emissions, energy demand, water consumption, resources consumption, efficiency, waste generation, etc.

Life Cycle Assessment is one of the most used standardized methodologies for estimating the environmental impacts linked to agricultural production (Audsley 1997; Canals et al. 2010; Milà i Canals 2003). However there are a limited number of fruit crop LCA studies, and they still do not present enough environmental information, or the impacts are partially analysed.

1.5. Agriculture and sustainability

As a response to the growing demand of an increasing population and worldwide economic interests, in last twenty years, the use of intensive farming practices have highly increased; so it has sponsored the influence of large companies to producing seeds and chemical fertilizers. The change from of traditional farming practices to intensive production has led important environmental problems as: soil erosion, water pollution, over-exploitation of water resources, and loss of biodiversity, pesticide-born damage and risk for human health.

Environmental degradation and food security crises suffered makes that today’s society is increasingly sensitized to environmental problems of the planet and makes responsible consumption, as well as the interest in consuming more sustainable and healthy foods. This consumer’s interest has generated that food producers change their production strategies toward more environmentally friendly products with the environment in order to in order to inform consumers of the environmental impacts of their products and processes and better position in the market.

In response to concerns about the environmental problems arising from intensive farming, developed countries and policy makers to address the problem have begun to offer alternatives to today's agriculture, and without giving up the goal of producing food in sufficient quantities. New agricultural models called “Good Agricultural Practices” have been promoted, based on respect for the environment and the obtaining healthier foods (FAO).Thus Good Agricultural Practices are those rules and techniques applicable to the farm focused on ensuring environmental sustainability, economic and social agricultural products. These practices includes the actions involved in the primary production of fruit, from land preparation to harvesting, the process of packaging or packing and transportation of these, in such a way that product safety is ensured.

European Commission is encouraging farmers to adopt integrated and organic production practices in order to develop sustainable agriculture (European Commission 2012) with the aim of promote sustainable European development. Integrated agriculture uses methods that are located halfway between conventional farming and organic farming. Integrated agriculture is based on the fair use of fertilizers, chemical fertilizers and treatments to control pests and diseases with optimized management of irrigation water. However organic production is completely restricted the use of synthetic chemicals. Both systems are regulated and have a control system common to all countries of the European Union.

In Europe the demand of consumers for sustaibanle agriffod products has increased by 35% between 2009 and 2014 (EUROSTAT ,2014), also supported by the emergence of specific eco-friendly labels and European healthy initiatives. By reason of the increasing consumer demand for more environmentally friendly and healthy food products real alternatives to current intensive production methods need to be supported by scientific research (Torrellas et al. 2012; Martínez Blanco 2012; Antón et al. 2007; Sanyé-Mengual et al. 2013; Torres et al. 2016).

1.6. Motivation of the dissertation

There are several published studies about environmental impact of crop production, but only few about fruit production, mainly due to a lack of data. Most of reviewed studies only consider one productive year, and initial stages of orchard establishment (soil preparation and planting) are not included. Distribution and consumption stages also are often not included in the study.

The most utilized methodology for estimating the environmental burdens linked to agricultural production is Life Cycle Assessment (LCA), nevertheless the number of studies related to fruit production is limited, and the impacts are partially analysed mainly due to a lack of data. The existing studies mainly focus on one or two productive year, when the life span of fruit orchards plantations is over 20 years.

Catalan Research Institute of Food and Agriculture Technology (IRTA), is an research organization located in Catalonia, which has a long history collaborating closely with farmers in order to improve performance and the techniques of its cultivation, all this has provided experimental data quality, especially for fruit production.

Considering that IRTA has available quality and for a long period of time, this dissertation aims to cover the research gaps related to environmental studies of the life cycle of fruit production, as well as contributing to improve the available methodology and data processing for agricultural products. All this, in order to identify the main environmental indicators and critical points among the life cycle of fruit production, because all the actors involved have information to improve their performance and environmental management.

1.7. Objectives of the dissertation

The aim of this dissertation is to assess an environmental analysis of fruit production, expressed in terms of Carbon footprint and Water footprint, considering the entire life cycle, from a sustainable perspective, to promote sustainable food production in order to contribute to get a sustainable development.

Carbon footprint and water footprint provide additional information on the characteristics of the products besides allowing companies to set goals for improving their production process and its environmental performance can also mean improved its image in the international market.

To achieve the target of the dissertation, the following goals have been described:

- **Objective I:** analyse the methodology available for Life Cycle Assessment, the carbon footprint and water footprint applied to agricultural production, and detect the variability of results depending on the data and methodology chosen.
- **Objective II:** Provide suggestions for improving the methodology for calculating carbon footprint and water footprint, so they can be applied to agricultural production. Analyse data processing and how it needs to be considered in agricultural inventories, in order to provide new information on fruit production.
- **Objective III:** Detect critical environmental points of the fruit production cycle, in order to provide environmental information to fruit sector actors involved, and to propose improvements in their process.

Chapter 2

Photography by SOSTENIPRA

Material and methods

Chapter 2. Material and methods.

This section introduces the different environmental tools that have been used in this work, to quantify the environmental impact related to fruit production: Life Cycle Assessment (LCA), Carbon Footprint (CF) and Water footprint (WF).

Table 2.1 Summary methodology applied in each Chaptershows a small summary of the methodology applied in each chapter of the dissertation. Further details can be found in the following chapters.

Table 2.1 Summary methodology applied in each Chapter

	Methodology applied		
	LCA	**CF**	**WF**
Chapter 3	•		
Chapter 4	•		
Chapter 5	•		•
Chapter 6	•	•	

2.1. Environmental assessment in agricultural products

Agriculture is a strategic and necessary human activity for any civilization that has been developing for many centuries. Until the mid-twentieth century, agricultural production was practiced in a natural way, using natural techniques and natural inputs. With the technological and industrial evolution that took place in the mid-twentieth century, and the growing population, it passed from extensive to intensive agriculture, introducing new production models more industrialized. So intensive agriculture models has highly contributed to the depletion of the natural resources and environmental impact

The main environmental problems related to agricultural activities can be grouped in the following types:

- Impacts related to energy consumption (global warming, resource depletion, etc.)
- Water pollution and depletion (nitrates, pesticides, etc.)
- Toxicity impacts (chemical products use)
- Decrease in soil quality (soil degradation, pollution, erosion,)
- Decrease of biodiversity in cultivated land

Today society is increasingly informed and more aware about making a sustainable and responsible consumption, generating a higher demand for environmentally friendly products, especially in what refers agricultural products. This consumer’s interest has changed consumption patterns and make that many food companies begin to consider to change their production models towards to sustainable production and reduce their environmental impact.

So environmental tools available can help food producers to detect and to quantify the environmental impact of their products and production processes

2.2. Environmental assessment tools

Below we present the different environmental tools and methodologies and approaches that have been used in this work: Life Cycle Assessment (LCA), Carbon Footprint (CF) and Water footprint (WF) to determine the environmental impact related of fruit production.

2.2.1. Life Cycle Assessment

Life Cycle Assessment (LCA) is defined as the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product, process or activity's life throughout its life cycle by (ISO 14040:2006). The life cycle is sectioned in stages that help the analytical process to obtain a detailed study and quantification of all inputs and outputs as they interact through processes into products and wastes.

The ISO 14040 guideline identifies three main stages when LCA is applied: 1) Definition of the system under study through goal and scope; 2) The inventory analysis and information compilation; 3) The impact assessment assignation. All of these stages are important for the assessment and are interrelated for the interpretation of results. The end results are dependent on the systems boundaries and the functional unit (FU), which is the unit to which the results of the LCA are related. Figure 2.1 shows the interrelation between the stages described by ISO 14040.

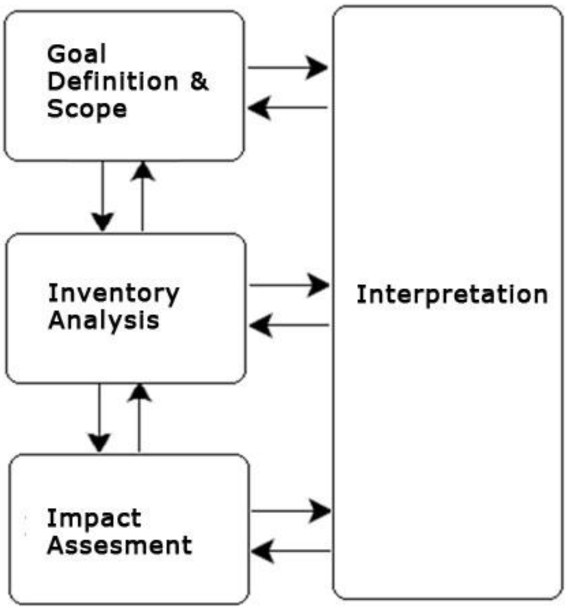


Figure 2.1 LCA Framework according ISO 14040:2006

Considering that characteristics of the system studied, and that the function of the orchard is to produce fruit, the FU choose is a “cultivation of 1kg of peach”. The fact of use a FU based in mass unit allows reflecting seasonal and yield variability.

Different orchards of peach and apple have been studied, and data of different productive years have been considered, in a range between 9-15 years. Data used in the inventory of this study is experimental data available from orchards of Catalan Research Institute of Food and Agriculture Technology (IRTA).

The impact categories considered in this study on the performance of LCA are mid-point characterization factors, and the calculation method used is Recipe Midpoint H, so the environmental flows were assigned by multiplying them by the corresponding characterization factor for different impact categories.

LCA calculations were performed using Simapro 8.0 software (Pré Consultants 2015) together with ecoinvent database 3.0 (ecoinvent Centre 2015). Environmental impact categories considered and their abbreviation are described in Table 2.2 .

Table 2.2 Environmental impact Categories used for LCA analysis

Abbreviation used	Impact category name	Units	Definition
ALO	Agricultural Land Occupation	m^2 x yr	Impact on the land due to agriculture. / Species loss, soil loss, amount of organic dry matter content, etc.
CC	Climate change	kg $CO_{2\ eq.}$	Alteration of global temperature caused by greenhouse gases. / Disturbances in global temperature and climatic phenomenon.
CED	Cumulative Energy Demand	MJ	Direct and indirect energy use. / Energy intensity of processes.
FD	Fossil Resource Depletion	kg oil $_{eq.}$	Decrease of the availability of non-biological resources (non- and renewable) as a result of their anthropogenic use. / Decrease of fossil resources.
FE	Freshwater Eutrophication	kg P $_{eq.}$	Accumulation of nutrients in freshwater systems. / Increase of nitrogen and phosphorus concentrations and formation of biomass
FET	Freshwater Ecotoxicity	kg 14DCB eq.	Toxic effects of chemicals on freshwater ecosystem. / Biodiversity loss and/or extinction of species.
HT	Human Toxicity	kg 14DCB $_{eq.}$	Toxic effects of chemicals on humans. / Cancer, respiratory diseases, other non-carcinogenic effects and effects to ionising radiation.
IR	Ionising Radiation	kg U 235 $_{eq.}$	Type of radiation composed of particles with enough energy to liberate an electron from an atom or molecule. / Effects of the radiation (health decline, cancer, illnesses, etc.).
ME	Marine Eutrophication	kg N $_{eq.}$	Accumulation of nutrients in marine systems. / Increase of nitrogen and phosphorus concentrations and formation of biomass.
MET	Marine Ecotoxicity	kg 14-DCB7 $_{eq.}$	Toxic effects of chemicals on marine ecosystem. / Biodiversity loss and/or extinction of species.
MRD	Mineral Resource Depletion	kg Fe $_{eq.}$	Decrease of the availability of non-biological resources (non- and renewable) as a result of their anthropogenic use. / Decrease of mineral resources.

NLT	Natural Land Transformation	m^2	Impact on the land due to agriculture, anthropogenic settlement and resource extractions. / Species loss, soil loss, amount of organic dry matter content, etc.
OD	Ozone Depletion	kg CFC-11 5 $_{eq.}$	Diminution of the stratospheric ozone layer due to anthropogenic emissions of ozone depleting substances. / Increase of ultraviolet UV-B radiation and number of cases of skin illnesses.
PMF	Particulate Matter Formation	kg PM10 eq.	Suspended extremely small particles originated from anthropogenic processes such as combustion, resource extraction, etc. / Increase in PM10 particles suspended on air.
POF	Photochemical Oxidant Formation	kg NMVOC6 $_{eq.}$	Type of smog created from the effect of sunlight, heat and NMVOC and NOX. / Increase in the summer smog.
TA	Terrestrial Acidification	kg $SO_{2\ eq.}$	Reduction of the pH due to the acidifying effects of anthropogenic emissions. / Increase of the acidity in water and soil systems.
TET	Terrestrial Ecotoxicity	kg 14DCB $_{eq.}$	Toxic effects of chemicals on terrestrial ecosystem. / Biodiversity loss and/or extinction of species.
ULO	Urban Land Occupation	m^2 x yr	Impact on the land due to anthropogenic settlement. / Species loss, soil loss, amount of organic dry matter content, etc.
WD	Water Depletion	m^3	Decrease of the availability of non-biological resources (non- and renewable) as a result of their anthropogenic use. / Decrease of water resource based on the total amount of water used.

Source :ecoinvent Centre 2015

2.2.2. Carbon footprint

According to Intergovernmental Panel Climate Change IPCC report 2007 (Barker 2007) the global anthropogenic GHG were 24% higher in 2004 compared to 1990 and 70% higher than in 1970. The IPCC 2007 report estimates agriculture's direct impacts to stand at about 10–12% of global emission.

Due to the increase of global warming that has occurred in recent years one of the important environmental indicators that have taken relevance is the emissions of Greenhouse Gases (GHG) related to products, it called Carbon Footprint (CF) is expressed as emissions of carbon dioxide equivalent ($CO_{2\text{-eq}}$).

CF is an indicator used to describe the amount of GHG emissions caused by a particular activity or entity, and thus a way for organizations and individuals to assess their contribution to climate change. It measures the total emissions of carbon dioxide in kilograms of $CO_{2\text{-eq}}$, generated during the life cycle of a product or service.

Figure 2.2 Carbon footprint symbol

2.2.2.1. Harmonization of Carbon Footprint concept

Standard PAS 2050, is a methodology developed by BSI British Standards institute (BSI Institute, 2008) and co-sponsored by the Carbon Trust and to calculate the CF of a product or a Service. PAS 2050 methodology sets out generic requirements for undertaking a GHG emissions assessment, such as transport, energy use, data quality rules; this means that sometimes not at all suited to specific scenarios and the results can be highly variable. In 20142 a review of PAS 2050 was published: PAS 2050-1:2012 (BSI. 2012) which provides supplementary requirements and additional guidance on those elements that have been found to present particular difficulties in horticultural context, such as land use change and allocation.

According to ISO 14067:2010 (Ferrandis 2015) CF is defined as: "the sum of greenhouse gas emissions and removals in a product system expressed as CO_2 equivalents, and based on a LCA using the single impact category of climate change". The ISO14067 definition has tried to harmonize the calculation of CF concept, regardless of other existing methodologies that defines in different way the system boundaries, therefore it can generate differences in the results, which is what this study wishes to determine. Table 2.3 shows the stages considered in different assessment: LCA, PAS and ISO and the difference between them.

Table 2.3 Stages considered in different assessments: LCA, PAS and ISO

STAGE	**ASSESSMENT**		
MINERAL FERTILIZERS PRODUCTION	**PAS 2050-1**	**LCA**	**ISO 14067**
Raw materials production and transport.	Included	Included	Included
Electricity and diesel.	Included	Included	Included
Chemical plant, machinery, maintenance and waste disposal.	Not included	Included	Included
Use emissions.	Included	Included	Included
AGRO CHEMICAL SUSBSTANCES PRODUCTION			
Raw materials production and transport.	Included	Included	Included
Electricity and diesel.	Included	Included	Included
Chemical plant, machinery, maintenance and waste disposal.	Not included	Included	Included
MATERIALS OR SUBTANCES TRANSPORT			
Diesel.	Included	Included	Included
Lorry, road production, maintenance and waste disposal.	Not included	Included	Included
Emissions.	Included	Included	Included
CULTIVATION INFRASTRUCTURE			
Buildings equipment, maintenance, waste disposal	**Not included**	**Included**	**Included**
Electricity and diesel.	Included	Included	Included
Material waste disposal.	Not included	Included	Included
CULTIVATION MANAGEMENT			
Diesel and electricity.	Included	Included	Included
Tractor and implements, machinery and maintenance.	Not included	Included	Included
Packaging.	Included	Included	Included
Fertilizers emissions.	Included	Included	Included
CONSUMABLES			
Use and manufacture	Included	Included	Included
IRRIGATION			
Water use and transportation	Included	Included	Included
Buildings and infrastructure	Not included	Included	Included

2.2.3. Water footprint

People consume a lot of water in their daily activities but it is important to reflect that the main consumption of water resources is linked to industries production processes. For many years the carbon footprint has been probably one of the best known public environmental indicators. Recently a new environmental footprint concept has introduced: Water Footprint (WF). The interest in the WF appears from the recognition that human impacts on water systems may be related, for human consumption, and that issues such as water scarcity or pollution can be better understood and managed considering production and retailers in its entirety (Chapagain, 2006).

Quantify the WF of a good or service can be useful information for consumers, retailers, traders and other agents that play an important role in supplying, particularly for goods that are water intensive, like food items, beverages, and textile materials (Canals et al. 2010). In water-scarce areas, knowing the WF of a good or service can be useful for determining how to make best use of the scarce water available (Aldaya and Hoekstra 2010).

In this study the WF will be calculated using Standard ISO14046:2015 (Ferrandis 2015), complemented with FAO guidelines, in order to quantify water consumption associated (directly and indirectly) with these products and the potential impacts of water use and associated pollution, as well as to detect the regional differences related to climate variations and crop evapotranspiration requirements.

Figure 2.3 Water footprint symbol

2.2.3.1. ISO 14046. Environmental Management. Water Footprint

Standard ISO 14046:2014 *"Environmental Management. Water Footprint. A principle, Requirements and Guidelines, is international water footprinting guidance"*. It forms part of the ISO 14000 series of environmental management standards. It is based on a lifecycle assessment as prescribed in ISO 14044:2006 , it assess and report the potential impacts of water use and pollution of products and processes, based on LCA. A water impact category is defined representing environmental issues of concern to which the lifecycle inventory analysis results may be assigned.

According the ISO 14046 requirements of water footprinting assessments should include: potential environmental impacts related to water, relevant geographical and temporal dimensions, quantity of water use and changes to water quality and information about local hydrology. The process can be modular, where the water footprint of different lifecycle stages can be summed to represent the water footprint, providing these are clearly defined and explained.

The elementary flows that WF which should include are:

- Quantities of water used.
- Resource types of water used.
- Temporal aspects of water use.
- Water quality parameters
- Forms of water use.
- Geographical location of water withdrawal.
- Emissions to air, water and soil with impact on water quality.

In this study direct water has been estimated as the inputs and outputs resulting from an organization's direct activities: irrigation, agricultural tasks, cleaning, storing. Indirect water has been estimated as inputs and outputs which are consequences of an indirect farmer's activities, but which arise from processes controlled by other organizations: production and processing of raw materials, transport of materials, fertilizer and pesticide manufacturing, waste management, materials use and production, energy, fuel and water supply and consumption, packaging materials and machinery production.

2.2.3.2. Water footprint FAO Guidelines approach

In the FAO Water Footprint approach three colour components are distinguished: green, blue and grey (Chapagain and Hoekstra 2004). The green component refers to rainwater stored in the soil. Blue component refers to surface and groundwater, and the grey water component is defined as the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards.

In this study the different colour water have been estimated in the following way according to According to Chapagain and Hoekstra (2004) specifications:

Green water has been estimated as the ratio of the green water use (m^3/ha) to the fruit yield (t/ha), where total green water use is obtained by summing up green water evapotranspiration over the growing period. The blue water is considered to be equal to the ratio of the volume of irrigation water used to the crop yield. The grey water has been calculated as the load of pollutants that enters the water system divided by the maximum acceptable concentration for the pollutant considered (kg/m^3) and the crop production (t/yr). So for fruit cultivation, for the grey component, it has been considered the water polluted as a result of the use of nitrogen fertiliser. The quantity of nitrogen that reaches ground or surface water has been assumed to be 10% of the applied fertilization rate in (kg/ha/yr.) (Chapagain and Hoekstra 2007). The consequence of the use other substances such as pesticides and herbicides has not been evaluated due a lack of data.

2.3. Economic assessment

In order to define which apple production system is better from economically point of view, it has conducted an economic assessment. The economic study is not intended to establish the cost of production of kg of fruit, but the comparison between different apple assay systems. It not takes into account possible differences in the life of the plantation.

In the economic analysis the following indicators are used:

NPV (Net Present Value): By the discount rate all annual balances generated by the investment are updated. It represents the present value of the retained earnings of the entire plantation life.

IRR (Internal Rate of Return): Annual average profitability of the plantation.

Internal rate of return is a metric used in capital budgeting measuring the profitability of potential investments. IRR makes the net present value (NPV) of all cash flows from a particular project equal to zero.

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o$$

Where:

Ct = net cash inflow during the period t
Co= total initial investment costs
r = discount rate, and
t = number of time periods

The analysis includes the following costs:

- Installation of drip irrigation system.
- Costs of manual work.
- costs of machinery labour.
- Costs of machinery acquisition.
- Rental costs of machinery specialized.
- Cost of insurance for crop losses by weather.
- Annual costs related with other work management.
- Administration costs and taxes.
- Planting cost: soil preparation, fertilization, materials, and installation of irrigation, labour and interest generated during the first year.

2.4. Case studies

Table 2.4 presents the details for each fruit (apple and peach). In both fruits, it has been considered different ranges of real production between (9-15 years). Cultivation is done using integrated fruit production practises according to (Morris and Winter, 1999). Integrated Production is defined as systems of agricultural production of quality food; using methods that respect the environment and human health in order to obtain high quality products minimize the use of agrochemicals. The two orchards chosen are in nearby areas but are geographically separated by a distance of 50 km, even the distance and the climatic conditions are similar.

Figure 2.4 shows boundaries of the System studied. The study includes all the phases involved in the fruit production: farming, retail, consumption and disposal, as well as the impact of the initial orchard establishment tasks (soil preparation and planting).

Table 2.4 Summary details for orchards studied.

System studied	
Fruit	Apple
Variety	*Malus domestica*
Location	Poal, Catalonia (North East of Spain)
Extension	1.5 hectares
Soil texture	Clay-loamy (USDA)
Annual temp. average	14.8ºC
Minimum temp.	-8.1ºC
Maximum temp.	38.4ºC
Annual rainfall average	372 mm
Annual average production	43.35 t/year.
Cultivation system	Integrated practices.
Data available	Period of 10 years

System studied	
Fruit	Peach
Variety	*Prunus persica L.*
Location	Gimenells, Catalonia (North East of Spain)
Extension	1 hectare
Soil texture	Loamy (USDA)
Annual temp. average	14.2ºC
Minimum temp.	-10.1ºC
Maximum temp.	39.2ºC
Annual rainfall average	350 mm
Annual average production	33.70 t/year
Cultivation system	Integrated practices.
Data available	Period of 10 years

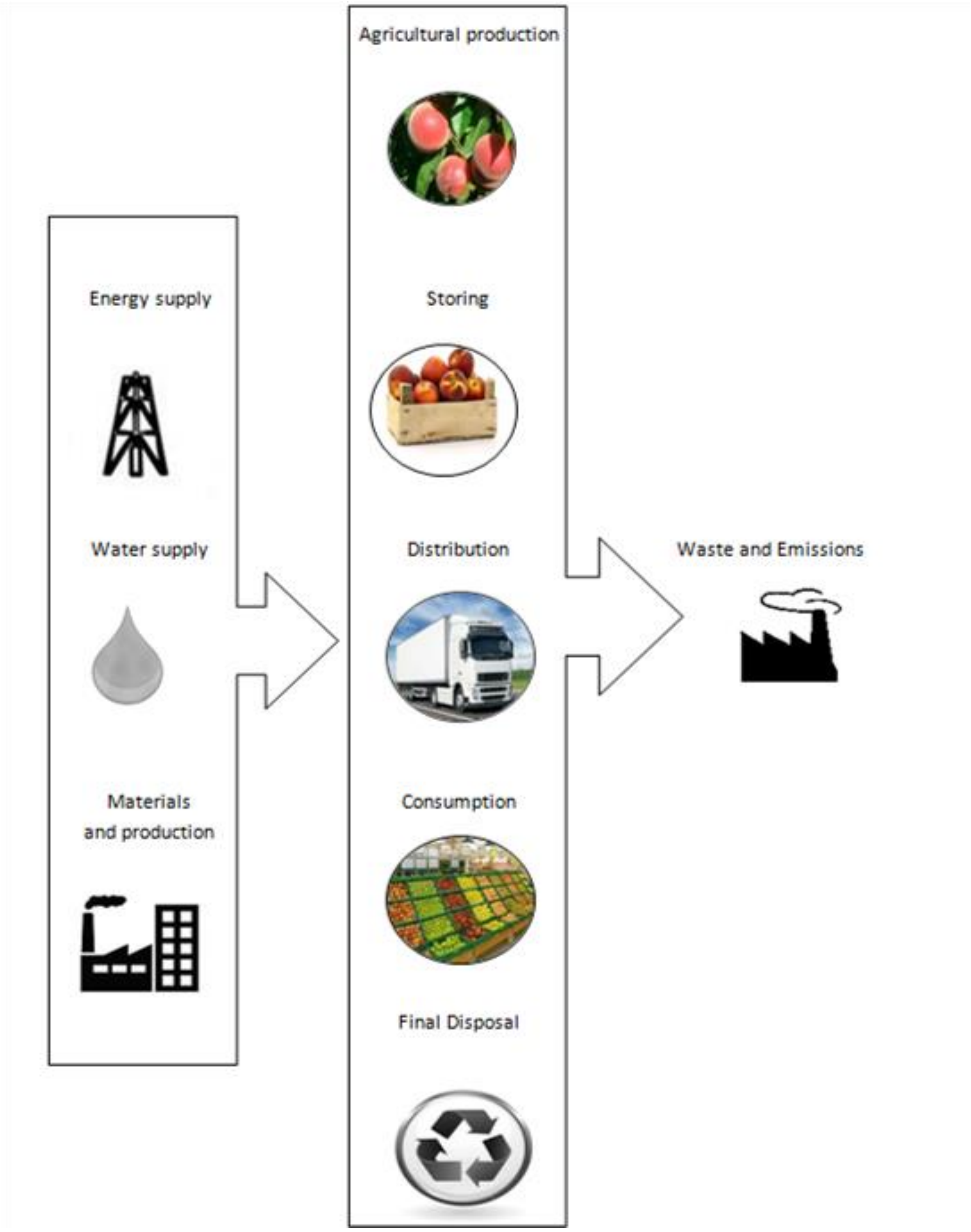


Figure 2.4 Boundaries of the Systems studied

2.5. Assumptions

Table 2.5 Details of the assumptions considered in the studypresents de details of the assumptions considered in the different chapters of this study, according to the literature and the data available, in order to apply the different methods described above and create the inventory:

Table 2.5 Details of the assumptions considered in the study

Input	Assumption	Source
Machinery	Number of machinery operations and the working hours for running the machines and their implements, was known. Emissions of machinery production and diesel consumed were estimated using information from ecoinvent database.	*Experimental data IRTA.* *ecoinvent database v.3.0 (Ecoinvent Centre).*
Electricity	The electricity consumed for irrigation pumps was known. The impact of generation and distribution of electricity demand was estimated using information from ecoinvent database according to the Spanish electricity mix of low voltage	*Experimental data IRTA.* *ecoinvent database v.3.0 (Ecoinvent Centre).*
Irrigation water	The orchard studied was irrigated with electric pumps, and the water came from a Catalan public irrigation canal (Catalonia-Aragon), water consumption was known.	Experimental data IRTA.
Irrigation system	The irrigation system for the fruit orchards is dropping system with an efficiency of 85% (Allen et al. 1998). It has been considered water networks average losses of 22% distribution according to (Canals et al. 2010) for the case of Spanish broccoli.	(Allen et al. 1998) (Canals et al. 2010)
Agrochemicals substances (insecticides and fungicides)	The active ingredients of the pesticides used have been taken into account according to experimental data. Individual pesticide production data were not available, thus the generic pesticide process from ecoinvent database.	Experimental data IRTA. ecoinvent database v.3.0 (Ecoinvent Centre).
Fertilizer production	The impact and the water involved in fertilizers production have been taken into account from ecoinvent database.	ecoinvent database v.3.0 (Ecoinvent Centre).
Fertilizer emissions	It has been considered the emissions of fertilizer production and the emissions of fertilizers used have been taken into account. Nitrogen (N_2O), phosphorus (P_2O_5) and potassium (K_2O) emissions were modelled according to the literature. Diffuse emissions, according Audsley (1997), it was assumed as 2% of NH_3 volatilization for simple nutrient fertilizer (ammonium nitrate), and 4% for multinutrient fertilizer (NPK). NO_x emissions were assumed as 10% of	(Bentrup 2001) (Audsley 1997)

	the N_2O emissions. The N_2O emission factor assumed for all fertilizers is 1.25% of N addition (Brentrup et al. 2001).	
Change Land Use	It was assumed that the land occupied is arable and that it had been used for agriculture for a long time. Therefore, no impacts caused by land transformation were taken into account as the plot has been an orchard for more than 25 years (ISO14067).	(ISO14067)
Carbon sequestration:	There is a lack of knowledge on specific topics, and in particular a lack of inventories to estimate carbon sequestration No specific land and biomass carbon sequestrations were taken into account in this work, as the soil carbon content remained constant during the years of the study, and there was no change in the use of the land. Biogenic carbon has not been considered as either kidnapped or as issued, because is for temporary short chain.	(Alaphilippe and Inra 2012)
Transport of input materials and substances to the orchard	It was assumed that the vehicle used to transport the materials and substances from the production plant to the local point of sale was a 7.5 t lorry, and the distance covered was 150 km. The vehicle considered to deliver the materials from the regional cooperative to the plantation was a small van <3.5t and the distance, 15 km. The impact related to the vehicles used was having been taken into account from ecoinvent database.	Experimental data IRTA. ecoinvent database v.3.0 (Ecoinvent Centre).
Fruit losses	According to Food and Agriculture Technology Institute (IRTA) experimental data the water losses during storing phases is quantified in 3%. The amount of fruit loss during distribution stage is accounted in 15%. Fruit waste and losses at houses is quantified with 17% (WRAP 2008).	Experimental data IRTA. (WRAP 2008)
Packaging materials	For packaging materials, the water used for plastic and cardboard box use was considered according ecoinvent database and experimental data.	Experimental data IRTA. Life Cycle Inventories of Packaging and Graphical Paper. ecoinvent 2007).

PART II

LIFE CYCLE ASSESMENT OF FRUIT PRODUCTS

Chapter 3

Photography by IRTA

Life Cycle Assessment of multiyear peach production.

Chapter 3. Life cycle assessment of multiyear peach cultivation.

Based on a manuscript by:
Vinyes, E., C.M. Gasol, L. Asin, S. Alegre, and P. Muñoz. 2015. Life Cycle Assessment of multiyear peach production. *Journal of Cleaner Production*. http://linkinghub.elsevier.com/retrieve/pii/S0959652615005880.

Abstract

Considering that peach is a significant fruit in the Mediterranean countries, and most publications on environmental impacts of fruit productions are based on one single productive year, this study attempts to perform an environmental analysis of peach production using Life Cycle Assessment, in order to provide new information on peaches, and also introduce a multiyear perspective analysis to identify the variability of the environmental impacts related to annual orchard yield and weather variations. The system studied is a peach orchard (Prunus persica L.) with integrated agricultural practices. The study analyses the cultivation period, as well as the impact of the initial orchard establishment tasks (soil preparation and planting). Data used have been collected directly from an orchard located in the North East of Spain, and covers 15 years of real production. The functional unit adopted was the cultivation of 1kg of peach. Four scenarios have been considered according to the different yield periods of the peach fruit tree: Growth, Low, High and Multiyear. The results of the study reveals that, depending on production scenario considered, the results per kg of peach can vary between 7% and 69% depending on the environmental indicator. If the impact of initial orchard establishment tasks (soil preparation and planting) is not included in the quantification, then 5% of total emissions may be overlooked, but sometimes a lack of data makes it difficult to include these stages. Caution should be taken when the functional unit is related to mass and only when a single year of production is studied, because unproductive years increase impacts on value per functional unit, whereas over-productive years decrease them. According to variability of the results obtained, multiyear approach should be considered in crops with an average life time of twenty years or higher. The present study can be considered a useful methodological framework for providing a deeper understanding of the key environmental impact issues related to fruit production based on peach case study, and how to avoid multiple interpretation of results associated to reporting annual environmental impact variations.

3.1. Introduction

The agricultural sector has changed in Europe over the last ten years, from traditional practices to more intensive methods, in order to increase the productivity of the plantations, and as a response to the growing demand of an increasing population. As a consequence of the increase of intensive methods, food production has become an important contribution to the depletion of natural resources and climate change (Martínez-Blanco et al. 2011) . The IPCC Climate Change Synthesis Report 2007 estimates that the direct impacts of agriculture contribute about 13.5% of global anthropogenic GHG emissions. Europe is currently encouraging farmers to practice more sustainable agriculture in order to meet all the needs of society: environmental, social and economic European Commission (2012). Even so, to promote environmental friendly agricultural production it is essential for farmers to identify the causes of environmental impacts of their production systems.

A few years ago, the main concern in the food industry was safety, but recently it is becoming conscious of the environmental repercussions of their products, and is attempting to open new horizons towards sustainable production. Consumers are also increasingly aware of the environmental performance of the food products they buy, and this is reflected in their purchasing decisions. To develop a proper environmental management for industries and farmers, it is essential to know the main environmental indicators of their products: emissions, energy and water consumption, waste generation, efficiency, etc. It can also give an environmental added value to their product, at the same time that it provides valuable information for consumers (Environdec 2015).

Table 3.1 shows a review of some publications about environmental impacts of fruit production. The literature review was carried out from papers in international journals and conference proceedings. The review covered all main aspects for conducting environmental analyses of fruit production systems, giving preference to the agricultural stage. The information was collected from two main approaches: LCA and agricultural aspects. For LCA approach the following items were considered: functional unit (FU), system boundaries, environmental impact assessment method, initial stages consideration, and cultivation period considered. For the agricultural approach, the country of the study, and fruit variety were taken into account.

Most of reviewed studies only consider one productive year, and initial stages of orchard establishment (soil preparation and planting) are not included. The application of environmental assessment methods in the fruit sector is conventionally divided into a field phase and a retail phase (considering a spatial time of one productive year). Although there are important differences in the environmental impacts in the field phase, a major part of the impacts is related to the distribution chain in the retail phase, mainly due to the cooling (Cerutti et al. 2013). Another important aspect to be considered is that some resources are used annually, whilst others are present during the whole lifetime of the orchard (Milà i Canals et al. 2006).

Table 3.1 Environmental fruit studies published in last 10 years

Fruit	Country	Tool	Method	Boundaries	FU	Period	Initial stage	References.
				EUROPE				
Apple	Switzerland	LCA	SALCA v.31	Production	ha, $	4 years	No	Mouron et al. 2006
Apple	France	LCA	CML EDIP97 IPCC 2007	Production	ha	1 year	No	Alaphilipe et al. 2012
Apple	Italy	LCA	EDIP	Production	kg	1 year	yes	Cerutti et al. 2013^{b}
Apple	Italy	LCA	CML01	Production & supply chain	kg	1 year	yes	Assomela 2012
Kiwi	Greece	LCA	CML01	Production & supply chain	kg	1 year	yes	Zeus 2012
Citrus (products)	Italy	LCA	IPCC GWP100 CML01	Production & processing	kg	1 year	No	Beccali et al. 2010
Orange	Spain	LCA	CML	Production	t	1 year	No	Sanjuán et al. 2005
Orange	Italy	LCA	Impact 2002+	Production & processing	kg	1 year	No	Clasadonte et al. 2010^{b}
Peach	Italy	LCA	Impact 2002+	Production & processing	kg	1 year	No	Clasadonte et al. 2010^{a}
Nectarine	Italy	EF	Eco indicator 99	Production	gha t^{-1}	1 year	No	Cerutti et al. 2010
Strawberry	Uk, Spain	Literature	IPCC 2007	Production & processing	kg	1 year	No	Williams et al. 2008
				OTHER COUNTRIES				
Apple	New Zeeland	LCA	EDIP97	Production & processing	t	2 years	yes	Milà Canals et al. 2006
Apple	Brazil, Uk	LCA	CML01 Baseline 2000	supply chain	t	1 year	yes	Sim et al. 2007
Cacao	Ghana	LCA	CML01	Production &	kg	1 year	No	Ntiamoah et

				processing				al. 2008
Pear	China	LCA	IPCC 2007	Production & processing	t	1 year	No	Liu et al. 2010
Orange	Brazil	LCA	EMS4 PIRA	Production & processing	kg	1 year	No	Coltro et al. 2009
Pineapple	Costa-Rica	LCA	PAS,2050 USEtox TRACI	Production & processing	kg	1 year	No	Ingwersen 2012
kiwi	New Zeland	CF	PAS 2050	Production & supply chain	kg	6 years	yes	Mc. Laren el al 2010

According Table 3.1, Life Cycle Assessment (LCA) is one of the most used standardized methodologies ISO14040 for estimating the environmental burdens linked to fruit production, and it has shown to be an effective mechanism to report environmental performance in the food and beverage sector in general (Vázquez-Rowe et al. 2012) . However there are a limited number of fruit crop LCA studies, and they still do not present enough environmental information, the impacts are partially analysed, and the existing studies mainly focus on one productive year, when the life span of fruit crop plantations range from 20 to 60 years. Quantitative environmental assessment methodologies such as LCA require significant time and resource inputs during the data acquisition and life cycle inventory (LCI) phase. Approaches to streamlining the LCI data collection process without degrading data quality are therefore required, and is especially true for agricultural products (Loiseau et al. 2014)) .The main reason that may explain this is due to environmental and energy aspects for the development of fruit crops were not taken in account by farmers during the last decades, so there is no available data and the existing information that can be found are not reliable data. In recent times, after the emergence of new private sustainability standards such as: Global Gap , 2014), SAGP Guidelines Principles, 2014), Sustainable Agriculture Initiative (SAI, 2014) and the growing competitiveness in the private markets, all the actors involved in fruit production showed much interest in environmental impacts that their products generate, and became aware of the need to collect much more reliable data to improve the quality, the availability and the temporality of these, in order to develop environmental studies with a high quality and rigorousness. Nonetheless, in the European context, the EU Framework Programme for Research and Innovation has been developed: Horizon 2020 , which encourages companies to develop more sustainable strategies in order to reduce the environmental impact of their companies and the use of resources. For the fruit sector in Mediterranean countries, the peach is an important product. The main producers of peaches in Europe are: Italy, Spain, Greece and France, all together produce 42% of the world production. According to (FAO statistics, 2013) the largest peach and nectarine producer is Italy with 1,474,337 tonnes, followed by Spain 1,129,300 tonnes, Greece 810,000 and France 313,300. While Italy stands out as the largest producer, Spain is the major exporter, due to its early season harvest, lower production costs, and varietal renewal using higher quality varieties. Greece is the major EU peach processor. Spain is the second peach and nectarine producer in the European Union, and ranks third in the world after China and Italy (European Commission 2012). This study will analyse the region of Catalonia, located in the North East of Spain, and is the region with the second highest peach production in Spain, with a production of 367,887 tonnes/year (t y^{-1}) and a cultivated area of 11,299 ha, which is 35% of the total Spanish peach production, and 26.4% of the total fruit cultivated area (MAGRAMA 2013).

The aim of this work is to calculate the environmental impact of a multiyear peach production system in the North East of Spain, using LCA methodology. Data used in the study have been directly collected from an experimental orchard, and fifteen years of production have been considered. This study is a peach analysis based on a multiyear system experiment, which allows working with a reliable and high-quality experimental dataset and supports to highlight the importance of the multiyear approach in order to reduce variability and underestimated environmental impacts. The results also may be useful to identify the hot spots of peach production in its agriculture stage, and provide new inventory data and results of Mediterranean peach fruit.

3.2. Materials and methods

The environmental analysis of multiyear peach production will be performed using LCA methodology according to Standard ISO 14040:2006.

LCA is defined by ISO 14040 as the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle. The end results are dependent on the systems boundaries and the functional unit (FU), which is the unit to which the results of the LCA are related, and used further for the communication of the LCA results.

The impact categories considered in this study on the performance of LCA are mid-point characterization factors, and the calculation method used is Recipe Midpoint H. In this method, the environmental flows were assigned by multiplying them by the corresponding characterization factor for different impact categories. Calculations were performed using Simapro 7.3.3 software, together with ecoinvent database 3.0.

In order to obtain scientific, verified, and comparable information about the environmental performance of the products, the results will be reported according to product category rules (PCR) procedures that have been developed in accordance with (ISO 14025 Procedures). Given that the scope of the study is fruit, the PCR model chosen will be: Fruits and nuts.

According to Recipe Midpoint (H) characterization method, the following environmental impact indicators were considered in the study:

- Climate Change (CCH) expressed in kg $CO_{2\ eq}$
- Ozone Depletion (ODP) expressed in kg CFC-11_{eq}
- Photochemical oxidant formation(PHO) expressed in kg NMVOC
- Terrestrial Acidification (TAC) expressed in kg $SO_{2\ eq}$
- Freshwater Eutrophication (FEU) expressed in kg P_{eq}
- Marine eutrophication (MEU) expressed in kg N_{eq}

- Agricultural land occupation (ALO) expressed in m2a
- Urban land occupation (ULO) expressed in m^2a
- Natural land transformation (NLT) expressed in m^2
- Water depletion (WDP) expressed in m^3
- Metal depletion (MDP) expressed in kg Fe_{eq}
- Fossil depletion (FDP)expressed in kg oil $_{eq}$
- Ecotoxicity (Etox) expressed in CTUe
- Demand for non-renewable energy resources (NRE) expressed in MJ_{-eq}

The indicators chosen are midpoint indicators. The classification and characterization stages were carried out excluding normalization, in order to avoid subjectivity in the analysis. The quantification of the ecotoxicity (Etox) indicator has been done according the USEtox model using Simapro software. USEtox is a model based on scientific consensus, providing midpoint characterization factors for human and freshwater eco-toxicological impacts of chemicals in life cycle impact assessment, developed under the United Nations Environment Program (UNEP) and the Society for Environmental Toxicology and Chemistry, (SETAC) Life Cycle Initiative UNEP-SETAC toxicity model, 2008 (Rosenbaum et al. 2008).

3.2.1. Functional unit

The choice of system boundaries, the definition of functional unit (FU), and allocation procedures plays an important role in the LCA of food products. The most commonly used functional unit is based on mass, but recently there are more ways of expressing the functional unit for food products, such as energy balance or protein content (Schau et al. 2008), and nutritional value (Martínez Blanco et al., 2011). A mass based functional unit is adequate when only analysing the agricultural stages of the life cycle of fruit for descriptive purposes (Milà i Canals et al. 2006). According to fruit and nuts PCR, and in order to compare the results according to yield variations over the years, a mass based functional unit has been chosen, so the FU was defined as a “cultivation of 1kg of peach. Considering that the function of the orchard is to produce, the fact of using an FU based on a mass unit also allows reflecting seasonal variability. A functional unit based on hectares could hide the variability of results.

3.2.2. Experimental orchard design

The demonstrative plantation studied is a peach orchard of *Prunus persica L.* It has an area of 1 hectare and is located in Gimenells (Lleida) in the North East of Spain. According to a USDA soil Survey (1999), the soil texture is loamy, and its physical proprieties are favourable for the root development, with fruit cultivation being possible. The orchard has a planting frame of 4x5m, the plot is designed with 15 rows of 20 trees (300trees/ha). Peach cultivation is done using integrated fruit production according to the European Integrated Farming Framework 2010. Integrated Production is defined as a system of agricultural production of quality food, using methods that respect the environment and human health in order to obtain high quality products, minimize the use of agrochemicals, optimize production methods and reduce waste.

The average yield of the orchard is 36,148 kg· ha^{-1} ±10%. Maximum production was achieved in year eight, with 48,350 kg· ha^{-1}, and the minimum was achieved in the second year, with a production of 18,745 kg· ha^{-1}

3.2.3. System description

The study only focuses on the cultivation period, but it also includes the initial establishment tasks: soil preparation and plantation. The nursery stage has been excluded, mainly due to the lack of reliable data regarding this phase of peach-growing. According to Vazquez-Rowe et al. 2012, given the longevity of the crops, and the small percentage of annual tree replacement, its exclusion should not significantly affect the final results. The agricultural stages considered in this study are: soil preparation and plantation, fertilization, irrigation, pest management, weeds mowing, pruning, and harvest. Post-harvest operations (storage, processing, packaging, and commercialization) are not included. Figure 3.1 System boundaries for cultivation of 1kg of peach.shows the boundaries of the system studied. Different management tasks are involved depending on the agricultural stage. Soil preparation and plantation tasks were performed mechanically with tractors (these tasks are only done once, at the beginning of the orchard when trees are planted). Agrochemicals were applied using a tractor and a sprayer. Fertilizers were applied through the irrigation system with electric pumps (fertirrigation). Pruning was done manually, and the wood was crushed with a tractor implement and incorporated into the soil (it is considered as a soil structuring effect). The emissions related to pruning waste degradation have not been considered. It has been assumed that biogenic carbon emitted, as well as the biogenic carbon fixed from the biomass of the tree or the peach, was not taken into account as a potential global warming indicator according to the ISO14067/ PAS2050-1. For this case study, the information about the effect of the pruning waste has on the soil was not available, however it is an interesting effect that will be considered for further research. Weed mowing was done with a tractor implement. Harvesting was done manually, but required a self-driven platform and a tractor to transport the fruit to the storehouse. Considering the characteristics of the system studied and all the tasks involved, the following inputs have been taken into account to make the inventory: production of fertilizers and their application to the field, pest management substances manufacture and their application (fungicides and insecticides), machinery manufacture and implements used with their transport to the orchard, water use, energy use (from irrigation pumps and inputs manufacturing).

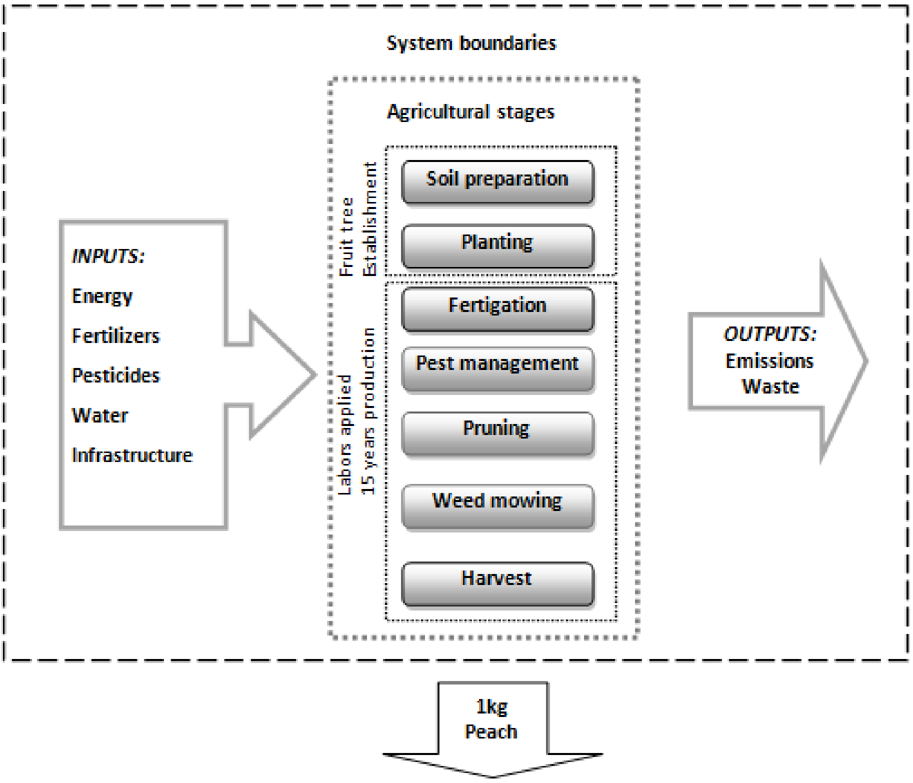


Figure 3.1 System boundaries for cultivation of 1kg of peach.

3.2.4. Inventory

Experimental data have been directly obtained from the Catalan Research Institute of Food and Agriculture Technology (IRTA) orchards. The data used to make the inventory cover 15 years of real production. Table 3.2 shows the inventory considered in the study, according to the FU described in Section 3.2.1 and also in Figure 3.1. As the FU chosen is related to the kg of fruit produced, four different production scenarios have been considered related to the different production periods of the fruit tree: *Growth, Low, High and Multiyear*, in order to analyse the variation of environmental results according to the orchard yield, all four scenarios are based on real data. The *Growth* scenario covers between years 1 and 3, when the orchard starts to produce fruit but has not yet reached full production. *Low* scenario covers when the fruit tree starts to go into full production between years 4 and 5. *High* scenario is when the orchard reaches the maximum fruit yield, around year 7. *Multiyear* scenario is the average of 15 years production.

The production considered for the Growth scenario is 18,745 kg ha-1, for Low it is 31,625 kg ha^{-1}, for High is 48,350 kg ha^{-1}, and the production considered for Multiyear is 36,280 kg ha^{-1}. The production ranges chosen are in line with the fruit growing study reported by Iglesias (2013). These scenarios are proposed to quantify the variability of LCA indicators depending on the consideration of a single year (productive or not) or a multiyear approach.

Table 3.2 Inventory for different FU production scenarios according to the FU

Production scenarios		**Growth**	**Low prod**	**High prod**	**Multiyear**
INPUTS					
From the technosphere					
Energy inputs	Units				
Diesel	g	8.49	6.11	4.48	6.04
Electricity	kwh	0.06	0.04	0.03	0.04
Transport	tkm	1.2	1.24	1.31	1.28
Materials inputs					
Fertilizers:					
K_2O	g	4.91	3.64	2.38	3.10
N_2O	g	4.96	3.68	2.40	3.14
P_2O5	g	0.67	0.51	0.33	0.43
Agrochemicals:					
fungicides (generic)	g	2.25	1.33	0.87	1.18
insecticides (generic)	g	0.56	0.33	0.22	0.30
Machinery:					0
Use	g	0.76	0.55	0.40	0.54
Accessories	g	0.05	0.04	0.04	0.05
Water	l	347.43	253.36	165.72	216.93
OUTPUTS					
To the technosphere					
Peach	kg	18,745	31,625	48,350	36,280
Emissions to the atmosphere					
Diesel:					
CO_2	g	25.95	18.67	13.71	18.47
SO_2	mg	4.98	6.04	4.44	5.98
VOC	mg	18.46	28.72	21.08	28.41
NOX	mg	169.28	268.67	197.23	265.79
NH_3	mg	0.07	0.12	0.09	0.12
CH_4	mg	0.42	0.77	0.57	0.76
N_2O	mg	0.41	0.72	0.53	0.71
Fertilizers:					
N_2O	mg	6.04E-03	4.48E-03	1.32E-04	5.20E-03
NH_3	mg	1.27E-02	9.41E-03	9.41E-03	1.09E-02

3.2.5. Data assumptions

Some assumptions have been made in order to optimize the calculation and the application of the methodologies:

- Change Land Use: It was assumed that the land occupied is arable and that it had been used for agriculture for a long time. Therefore, no impacts caused by land transformation were taken into account as the plot has been an orchard for more than 25 years (ISO14067).

- Agrochemicals substances (insecticides and fungicides). The active ingredients of the pesticides used have been taken into account. Individual pesticide production data were not available, thus the generic pesticide process from ecoinvent database v3.0 has been chosen (ecoinvent Centre).

- Machinery: Experimental data of the number of machinery operations and the working hours for running the machines and their implements have been used to quantify the amount of machinery input per kg of fruit. Emissions of machinery production and diesel consumed for machinery operations have also been taken from ecoinvent database v.3.0 (Ecoinvent Centre).

- Electricity: The electricity consumed for irrigation pumps was known, and the impact of generation and distribution of electricity demand was estimated using information from ecoinvent database v3.0, according to the Spanish electricity mix of low voltage (ecoinvent Centre).

- Irrigation water: The orchard studied was irrigated with electric pumps, and the water came from a Catalan public irrigation canal (Catalonia-Aragon).

- Fertilizer emissions: It has been considered the emissions of fertilizer production and the emissions of fertilizers used have been taken into account. Nitrogen (N_2O), phosphorus (P_2O_5) and potassium (K_2O) emissions were modelled according to the literature (Brentrup 2001; Audsley 1997). As regards diffuse emissions, according Audsley (1997), it was assumed as 2% of NH_3 volatilization for simple nutrient fertilizer (ammonium nitrate), and 4% for multinutrient fertilizer (NPK). NO_x emissions were assumed as 10% of the N_2O emissions. The N_2O emission factor assumed for all fertilizers is 1.25% of N addition (Bentrup, 2001).

- Transport of input materials and substances to the orchard: It was assumed that the vehicle used to transport the materials and substances from the production plant to the local point of sale was a 7.5 t lorry, and the distance covered was 150km. The vehicle considered to deliver the materials from the regional cooperative to the plantation was a small van<3.5t and the distance, 15km.

- Carbon sequestration: there is a lack of knowledge on specific topics, and in particular a lack of inventories to estimate carbon sequestration (Alaphilipe et al., 2012)**.** No specific land and biomass carbon sequestrations were taken into account in this work, as the soil carbon content remained constant during the years of the study, and there was no change in the use of the land. Biogenic carbon has not been considered as either kidnapped or as issued, because is for temporary short chain.

3.3. Results and discussion

The results obtained are based on the FU (production of 1kilogram of peach) and according to the impact indicators defined in Section 2.1. Results and discussion are organized into three sections: 3.3.1 LCA results, 3.3.2 Agricultural stages impact contribution, 3.3.3 Annual evolution of impacts

3.3.1. LCA results

Figure 3.2 shows relative percentage values of all impact categories analysed according to scenarios considered. Large differences between 30-50% were identified in the environmental impact values depending on the production scenario (Growth, Low, High and Multiyear). *High* scenario presents the lowest impact in relative percentage in all impact categories, because the maximum yield is achieved in this scenario, thus the amount kg of peach produced is higher than other scenarios (48,350 kg.ha^{-1}), so the impact associated per kg of fruit becomes lower. *Growth* scenario has the highest relative percentage in all impact categories, as the kg of fruit produced is very low (18,745 kg.ha^{-1}), thus the impact associated per kg of fruit produced becomes the highest.

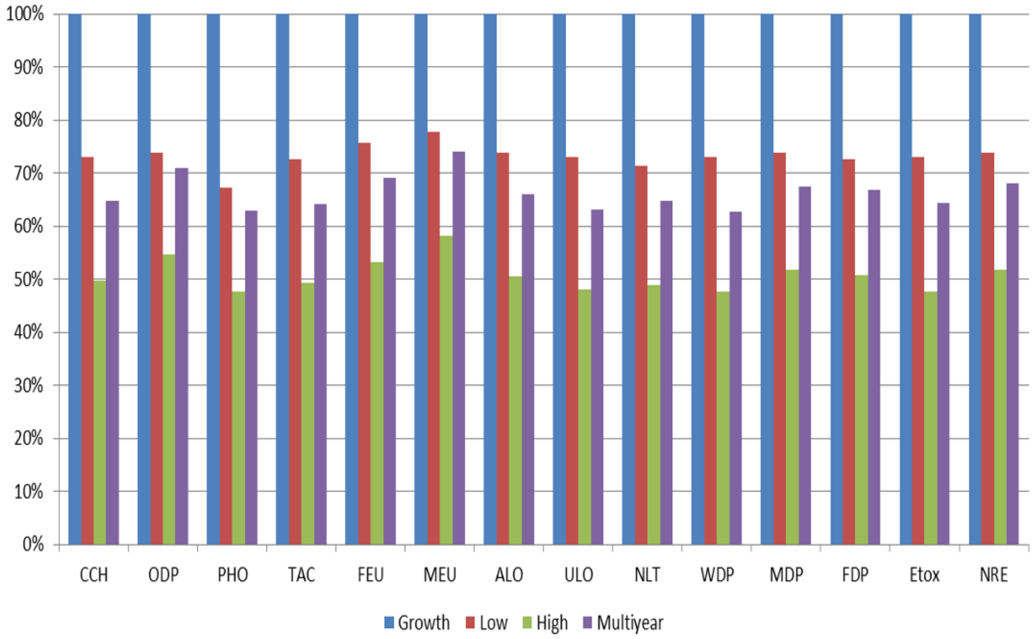


Figure 3.2 Relative impact values per FU depending on the production scenarios considered.

3.3.2. Agricultural stages impact contribution

Table 3.3 Total and relative percentage impact values per FU depending on the production scenarios shows the results of total impact values and agricultural stages contribution expressed in % for each impact category studied, and according to the production scenario (*Growth, Low, High and Multiyear*). Depending on the scenario considered, the percentage contribution of each impact category can vary between 7%-69%. Impact values per FU for all agricultural stages studied become higher if they are calculated according to *Growth* and *Low* scenarios because the kg of peach produced in this scenario are lower. In the impact categories required in Fruit and nuts PCR a range of variance can be observed in the results: NRE 8-52%, GWP 11-50%, WDP 14-52% and Etox 12-69%.

Of the all agricultural stages considered in the study, fertirrigation is the stage that presents the highest contribution percentage in 10 of the 14 impact categories studied for all scenarios, with a maximum contribution of 99.93% in WDP category (Growth scenario) and a minimum contribution of 45.66% in FDP category (Multiyear scenario). Pest management presents the highest contribution in the 4 remaining impact categories, with a maximum of 64.50% in Etox (Growth scenario) and a minimum of 47.22% in ODP. Fertilizer dosages are calculated according to the requirements of the fruit tree, and the maximum potential yield expected for each year according to the variation in annual conditions (age of the orchard, soil analysis results and climatic conditions); thus, every year a maxim value of fertilizers dosage is defined for the orchard, because once the maximum dose is exceeded it does not guarantee higher yield.

If the soil preparation and planting stages are not included in the calculation, then the 5% of total emissions can be overlooked, considering that the life span of peach plantation of 15 years. However they are distributed over the fifteen years of production (these tasks are only done once, at the beginning of the orchard when trees are planted). Cerutti (2013[a]) reported that orchards are perennial and biological systems, and these two characteristics add complexity to the modelling of fruit systems. But if the productive period alone is considered, the environmental impacts of the final product are underestimated considerably. The longer the life span of the peach crop plantation, the lower is the contribution of initial agricultural stages such as soil preparation and planting. Milà I Canals (2006) stress that it is important to consider the nursery in environmental impact assessments, but a lack of data makes this difficult. According to Cerutti (2013[a]), the nursery where orchard seedlings are produced should be considered an upstream process delivering grafted plants to the orchards, and the impact during this stage should be included in assessments of fruit production systems, even if impacts are spread over the lifetime of the orchard. This has not been included in this study due to the lack of available experimental information.

Results obtained were compared with other publications of fruit production with similar agricultural stages and life span such as: apple, orange and peach production. The impact percentage contribution of the agricultural stages considered in the study are consistent with the results described for other fruit studies described I Table 1 such as Sanjuán (2005), Coltro (2009), Clasadonte (2010[a,b]) and Alaphilipe (2012). It should be mentioned that the aforementioned publications only considered productive periods for one year. The existing studies for peach fruit are related to Eco indicators, so it has not been possible to validate and compare the total impact values obtained in this study because there are no existing peach studies focused on mid-point characterization factors.

Once the environmental impact of the different agricultural stages is evaluated, and taking into consideration that fertirrigation is the stage that presents the highest contribution percentage in 10 of the 14 impact categories studied for all scenarios (this is because manufacturing of fertilizers have a significant impact), it would be interesting for farmers to try and choose another kind of fertilizer with low environmental impact and encourage them to try to adjust the application dose, with better the monitoring of nutrients contents in soil and crop. Other important recommendations for farmers, in order to promote orchard better environmental performance are: the orchard design (trees orientation, planting frame, irrigation system) and geographic location, in order to reduce water consumption and pesticides use.

Table 3.3 Total and relative percentage impact values per FU depending on the production scenarios

Impact category Units		**Soil prep** % total	**Planting** % total	**Fertirrigation** % total	**Pest m.** % total	**Pruning** % total	**Moving** % total	**Harvest** % total	**TOTAL**
Growth									
kg $CO_{2\,eq}$	CCH	0.42	0.58	70.22	21.66	0.86	1.71	4.54	2.50E-01
kg CFC-11$_{eq}$	ODP	0.46	0.57	43.89	47.22	0.95	1.89	5.02	2.81E-08
kg NMVOC	PHO	1.91	2.27	0.00	64.47	3.78	7.55	20.02	3.44E+04
kg $SO_{2\,eq}$	TAC	0.52	0.65	67.14	23.10	1.04	2.07	5.49	1.64E-03
kg P_{eq}	FEU	0.15	0.23	66.06	30.48	0.37	0.74	1.97	5.65E-05
kg N_{eq}	MEU	0.44	0.53	40.33	51.45	0.87	1.75	4.63	1.12E-04
m^2a	ALO	0.12	0.20	79.31	17.71	0.32	0.64	1.70	2.33E-03
m^2a	ULO	0.04	0.05	96.12	3.05	0.09	0.18	0.47	5.45E-03
m^2	NLT	0.73	0.89	56.47	29.68	1.47	2.95	7.81	6.87E-05
m^3	WDP	0.00	0.00	99.93	0.06	0.00	0.00	0.01	3.21E-01
kg Fe_{eq}	MDP	0.34	0.60	61.84	29.30	0.96	1.90	5.06	1.52E-02
kg oil$_{eq}$	FDP	0.71	1.16	48.64	37.39	1.46	2.92	7.73	5.21E-02
CTUe	Etox	2.42	0.94	0.00	64.50	3.77	7.55	20.00	5.98E+03
MJ	NRE	0.86	1.76	55.94	30.58	1.41	2.81	7.46	2.38E+00
Low									
kg $CO_{2\,eq}$	CCH	0.34	0.47	70.74	20.23	0.70	1.39	6.15	1.83E-01
kg CFC-11$_{eq}$	ODP	0.37	0.46	39.81	50.39	0.76	1.48	6.73	2.08E-08
kg NMVOC	PHO	1.68	2.00	0.00	56.75	3.33	6.65	29.60	2.31E+04
kg $SO_{2\,eq}$	TAC	0.42	0.53	68.16	20.85	0.85	1.68	7.51	1.19E-03
kg P_{eq}	FEU	0.11	0.18	64.37	31.97	0.29	0.58	2.49	4.28E-05
kg N_{eq}	MEU	0.33	0.41	38.20	53.17	0.66	1.33	5.90	8.75E-05
m^2a	ALO	0.10	0.16	77.97	18.80	0.26	0.51	2.20	1.72E-03
m^2a	ULO	0.03	0.04	96.03	3.06	0.07	0.14	0.62	3.98E-03
m^2	NLT	0.61	0.73	57.81	26.39	1.22	2.39	10.85	4.91E-05
m^3	WDP	0.00	0.00	99.93	0.06	0.00	0.00	0.01	2.34E-01
kg Fe_{eq}	MDP	0.27	0.48	61.48	29.16	0.77	1.52	6.31	1.12E-02

kg oil $_{eq}$	FDP	0.58	0.95	49.11	35.29	1.19	2.33	10.54	3.78E-02
CTUe	Etox	1.96	1.43	0.00	52.44	3.07	6.13	34.97	4.36E+03
MJ	NRE	0.69	0.75	55.48	29.75	1.13	2.21	9.98	1.76E+00
High									
kg CO$_{2\ eq}$	CCH	0.32	0.45	67.87	21.60	0.75	1.41	7.60	1.25E-01
kg CFC-11 $_{eq}$	ODP	0.33	0.40	35.19	54.42	0.67	1.34	7.65	1.42E-08
kg NMVOC	PHO	1.56	1.84	0.00	52.39	3.07	6.14	35.00	1.07E+04
kg SO$_{2\ eq}$	TAC	0.41	0.51	65.64	21.70	0.82	1.63	9.29	7.32E-04
kg P $_{eq}$	FEU	0.11	0.17	59.83	36.01	0.27	0.54	3.08	2.92E-05
kg N $_{eq}$	MEU	0.29	0.36	33.44	57.53	0.58	1.16	6.63	6.11E-05
m^{2}a	ALO	0.09	0.15	74.47	21.74	0.25	0.49	2.80	1.14E-03
m^{2}a	ULO	0.03	0.04	95.37	3.54	0.07	0.14	0.81	2.60E-03
m^2	NLT	0.58	0.70	55.23	26.67	1.17	2.34	13.32	2.91E-05
m^3	WDP	0.00	0.00	99.91	0.07	0.00	0.00	0.01	1.53E-01
kg Fe $_{eq}$	MDP	0.25	0.45	57.22	31.81	0.72	1.42	8.13	7.24E-03
kg oil $_{eq}$	FDP	0.54	0.89	45.82	36.74	1.11	2.22	12.68	2.31E-02
CTUe	Etox	1.96	1.43	0.00	52.45	3.07	6.13	34.96	1.86E+03
MJ	NRE	0.65	0.70	51.64	31.84	1.06	2.12	11.99	1.09E+00
Multiyear									
kg CO$_{2\ eq}$	CCH	0.36	0.50	68.09	21.73	0.80	1.53	6.98	1.62E-01
kg CFC-11 $_{eq}$	ODP	0.36	0.36	36.38	53.57	0.74	1.48	7.02	2.00E-08
kg NMVOC	PHO	1.69	1.69	0.00	54.60	3.34	6.68	31.69	2.16E+04
kg SO$_{2\ eq}$	TAC	0.45	0.45	65.48	22.30	0.90	1.79	8.51	1.05E-03
kg P $_{eq}$	FEU	0.12	0.12	60.58	35.39	0.30	0.60	2.83	3.90E-05
kg N $_{eq}$	MEU	0.33	0.33	34.17	56.91	0.66	1.31	6.22	8.32E-05
m^{2}a	ALO	0.10	0.10	75.08	21.28	0.27	0.54	2.56	1.54E-03
m^{2}a	ULO	0.04	0.04	95.42	3.53	0.08	0.15	0.73	3.44E-03
m^2	NLT	0.63	0.63	54.68	28.16	1.26	2.52	11.99	4.46E-05
m^3	WDP	0.00	0.00	99.92	0.07	0.00	0.00	0.01	2.01E-01
kg Fe $_{eq}$	MDP	0.28	0.28	57.69	31.75	0.79	1.57	7.42	1.03E-02
kg oil $_{eq}$	FDP	0.59	0.59	45.66	37.67	1.21	2.42	11.49	3.49E-02
CTUe	Etox	2.09	1.52	0.00	55.09	3.26	6.52	31.51	3.85E+03
MJ	NRE	0.71	0.71	51.44	32.49	1.23	2.48	10.90	1.62E+00

3.3.3. Annual evolution of impacts

This section describes the annual evolution of the impact categories recommended for Fruit and Nuts PCR: a) Non-renewable resources, b) Global warming potential, c) Water depletion, and d) Ecotoxicity during the 15 years of life span of peach orchard.

From year 1 to year 4 orchard is not very productive because the fruit tree is getting stabilized, from year 5 it starts to come into full production. Between years 6 to 12 it reaches the stable production. From year 13 to 15 the orchard begins to lose efficiency until year15 when it ceases to be productive and acquires the finest of its useful life. Note that in the first year (year 1) there is no fruit production, so results are discussed from second year; maximum production was achieved in the year 8 with 48,350 kg· ha^{-1} and the minimum was achieved in the year 2, with 18,745 kg· ha^{-1}. Note that annual yield variability not only depends on the orchard age, it also depends on the meteorological conditions, so the fact of considering a range of years allows these variables to be reflected on the yield.

The climatic conditions are an important fact to be considered in agricultural practices when annual variation is studied, because weather has an effect on many aspects of fruit production such as: yield, water requirements, pest management and weed mowing. Thus, it is important to have meteorological inventory with local data evolution, in order to evaluate the multiyear approach. The fact of studying 15 years of real production, means that the variability of the climatic conditions are more reflected in the results than if we only had studied a single year of production. Note that the yield variations not only depend on the orchard age, it also strongly depends on other variables, such as fruit variety, geographic location, planting frame, climatic conditions, irrigation system, fertilizer supply and pest control optimization. Therefore, it is important to have data related to these other variables and for as long a period of time as possible to as to reflect them in the results.

a) Non-renewable energy resources (NRE)

Figure 3.3.a represents the energy consumed in terms of $MJ.ha^{-1}$ consumed for the inputs considered during 15 years. It also can be observed. The evolution of MJ per kg of peach per year (dashed line) can also be observed in the Graph. As regards the MJ required to produce 1 kg of peach, it can be observed that during the second year the value is very high around 4 $MJ·kg^{-1}$, but from the second year onwards fruit yield per hectare begins to increase, then the MJ. kg^{-1} decreases, reaching a minimum value in year 8 of around 1.8 $MJ·kg^{-1}$ (in this year the maximum yield is achieved). Concerning the values of the $MJ.ha^{-1}$ for inputs considered, it can be observed that they are inversely proportional to the kg produced. Fertilizers are the input with the highest contribution in this category during the fifteen years considered, due to the energy needed for their manufacturing. In the second year the $MJ.ha^{-1}$ has a minimum of 3.8 E+04 $MJ.ha^{-1}$, as fruit trees are not very productive low fertilization is needed, just the dose to promote the correct development of the crop but no the fruit. On the other hand during years 8-10 the maximum yield is achieved, so more fertilization is needed to promote fruit

development, in consequence the MJ.ha$^{- 1}$ consumed has a maximum value 6.5 E+04 MJ.ha^{-1}. Between years 10 to 12 the MJ.ha^{-1} tends to stabilize because as the kg produced becomes stable so fertilizers dose also becomes stable. In years 14 and 15 the MJ.ha$^{- 1}$ consumed decreases, because the orchard starts to become unproductive, so less agricultural tasks are invested due to fruit yield decrease.

b) Climate change (CCH)

Figure 3.3.b quantifies the emissions in terms of kg CO$_{2eq.}$ha^{-1} for the inputs considered during 15 years, and also illustrates the evolution of the kg CO$_{2eq}$ per kg of peach and year. Regarding to the kg CO$_{2eq}$ emitted to produce 1 kg of peach it can be observed that during the second year the maximum value is achieved 0.37 kg CO$_{2eq}$ ·kg^{-1}, but from the second year onwards fruit yield begins to increase, then the kgCO$_{2eq}$ ·kg^{-1} decreases getting the minimum value in year 8 around 0.16 kgCO$_{2eq}$·kg^{-1}. When fruit yield begins to be constant then kg CO$_{2eq}$ per kg of peach value decreases and then tends to stabilize (0.15-0.20 kgCO$_{2eq}$·kg^{-1}). About the values of kg CO$_{2eq.}$ha^{-1}, once more fertilizers are the input with the highest contribution for the fifteen years considered, due mainly to the high emissions related to their manufacturing process. The maxim value is achieved in year 8 with 6E+03 kg CO$_{2eq.}$ha^{-1}. This year is when more fertilization is needed to promote fruit development, and more machinery hours and more diesel consumption is required to collect the kg of fruit produced; and on the contrary the minimum is in year 2 with 3.5E+03 kg CO$_{2eq.}$ha^{-1} when less fertilization, machinery and diesel are involved.

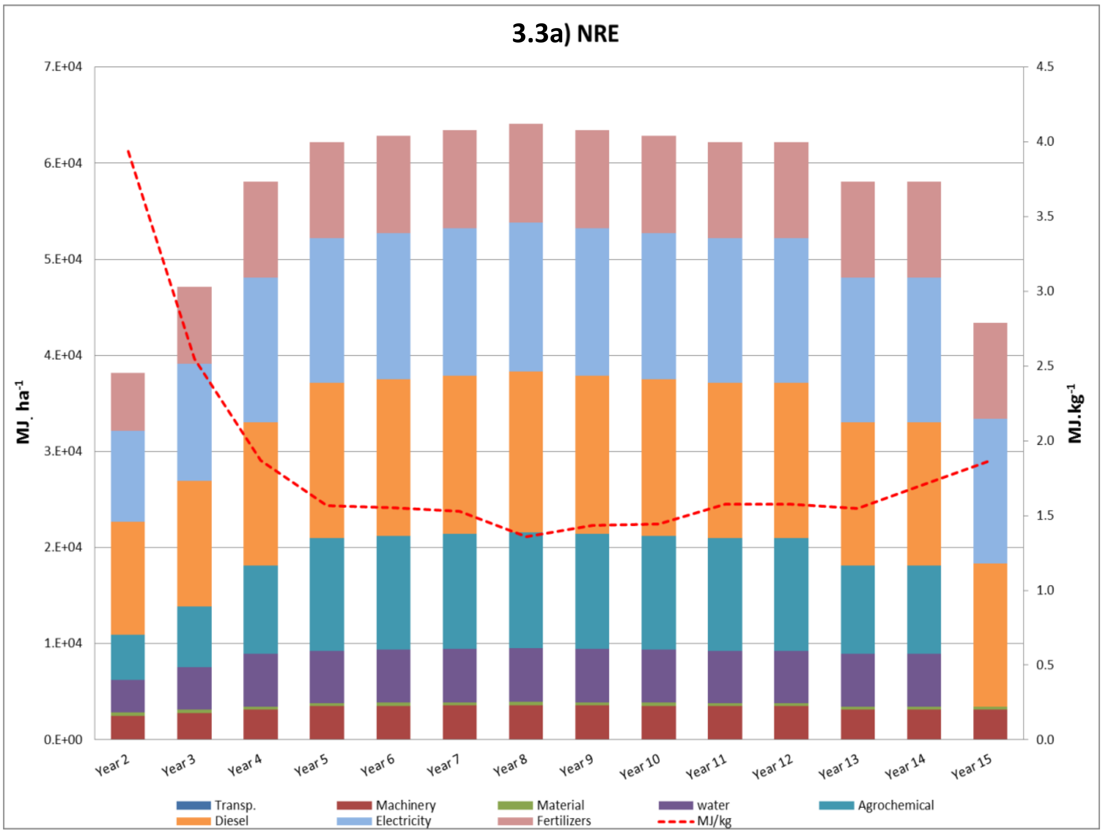
c) Water Depletion (WDP)

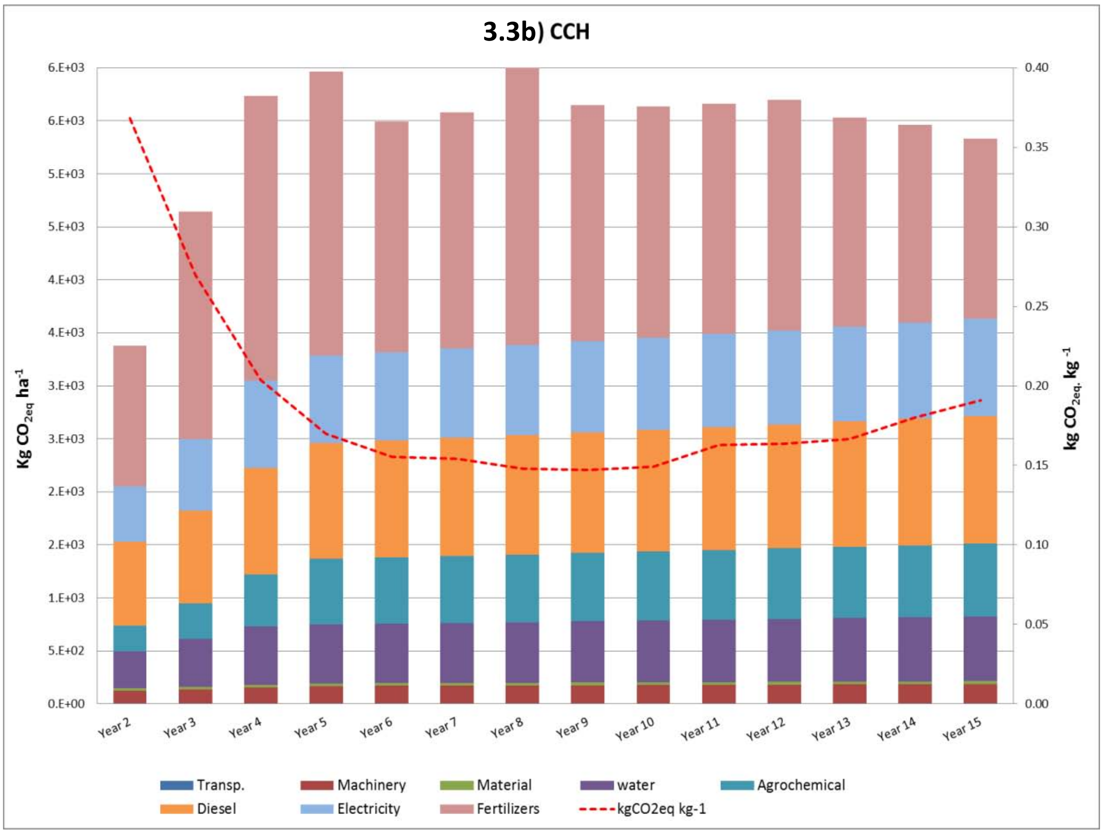
Figure 3.3.c represents the m^3.ha^{-1} consumed for the inputs considered during 15 years, and the m^3 per kg of peach and year. It can be observed that the maximum m^3 consumed to produce 1 kg of peach is in the second year, 0.5 kg CO$_{2eq}$ ·kg^{-1}, then as fruit yield begins to increase, the m^3.kg^1 decreases, reaching the minimum value in year 8 of around 0.2 kgCO$_{2eq}$·kg^{-1}. As regards the inputs considered, in this category, water has the highest contribution during the fifteen years, due to the amount of water needed for the irrigation. The minimum value of m^3.ha^{-1} is achieved in the second year with 1.6E+03 m^3.ha^{-1} and this is also the year when low irrigation is required because tree requirements are lower due to it not being a full productive year. The maximum value is achieved in year 8 with 1.8E+04 m^3.ha^{-1}, as $^{\text{this}}$ is the year when high irrigation is needed to help to promote fruit progress. Between years 6-13 the quantification of m^3.ha^{-1} tends to be stable because the yield is stable, and as agricultural management tasks are constant, it starts to decrease at years 14-15, when the yield and water requirements become lower.

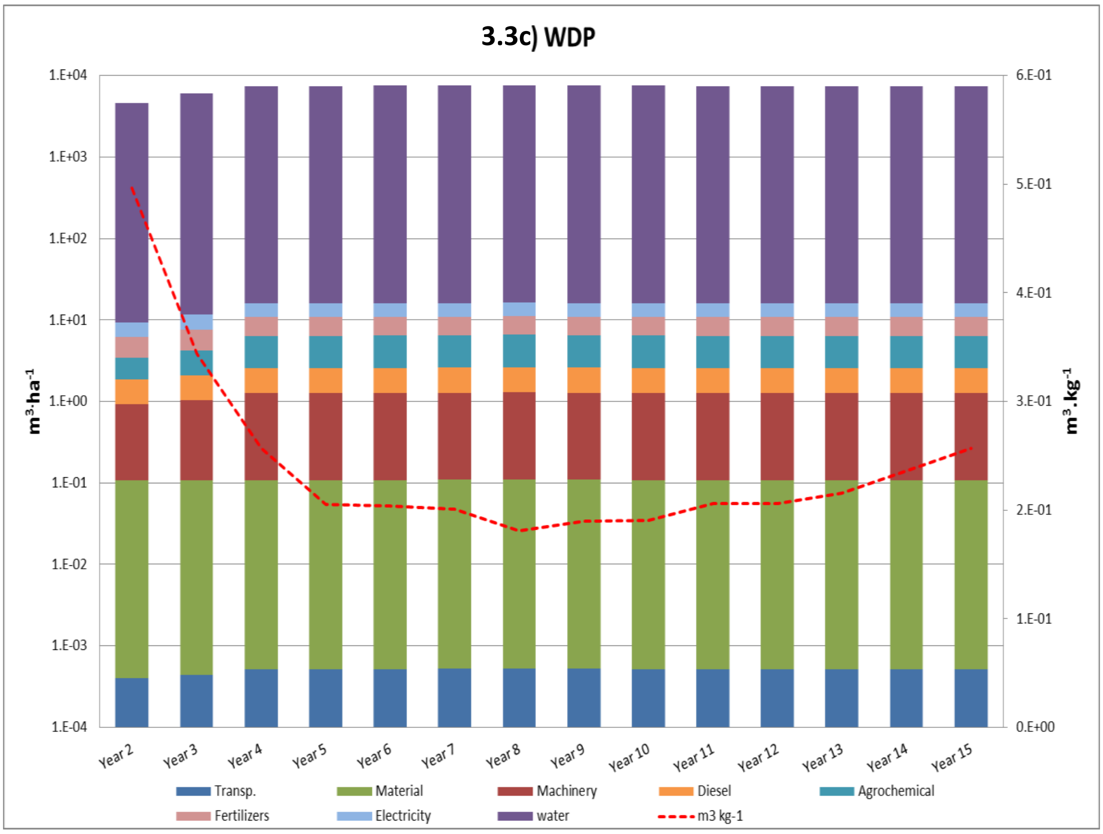
d) Ecotoxicity (Ecotox)

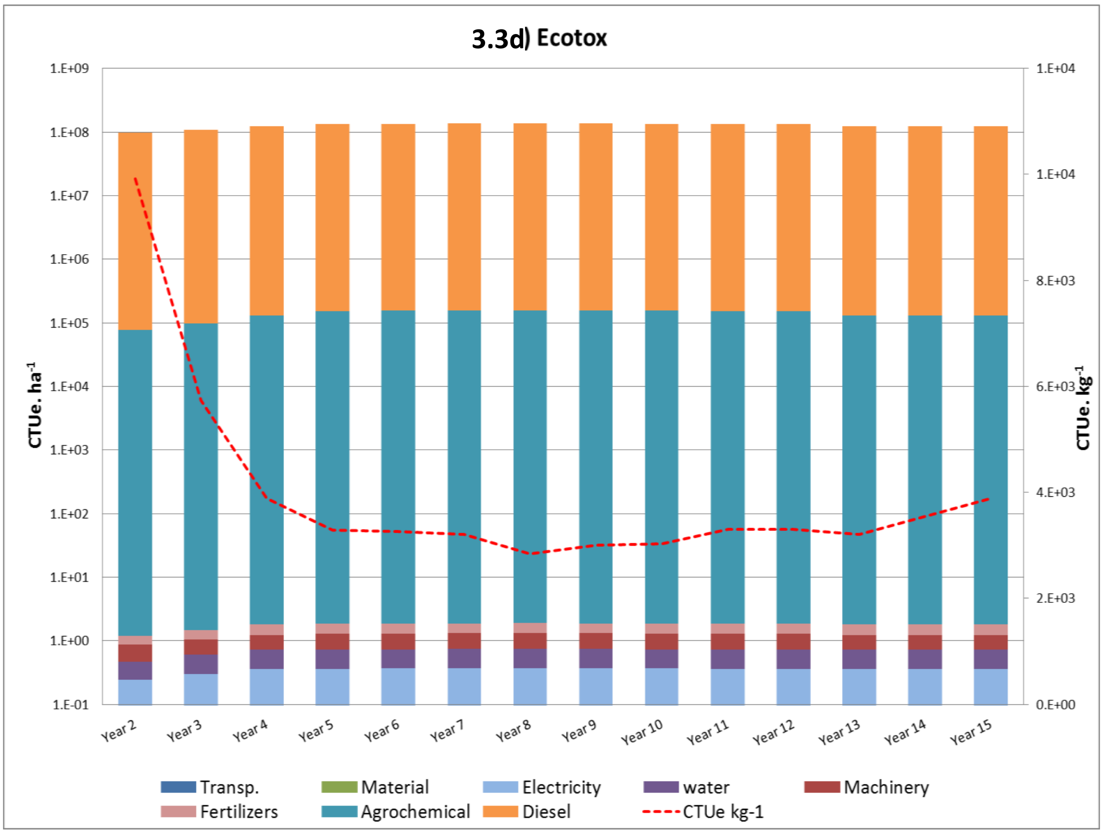
Figure 3.3.d represents ecotoxicity impact in CTUe.ha^{-1} for the inputs considered for 15 years, and also CTUe.kg^{-1} per kg of peach and year. In this category, once more, the maximum impact to produce 1 kg of peach is in achieved in the second year, 1.E^{+04} CTUe ·kg^{-1}, and reaches a minimum value in year 8, 4.E^{+03} CTUe ·kg^{-1}. As regards the inputs considered in the values of CTUe.ha^{-1}, diesel consumption has the highest contribution during the fifteen years, due mainly to the high ecotoxicity of some of its chemical components. The maxim value of CTUe.ha^{-1} is achieved in year 8 with 1.2E+08 CTUe.ha^{-1}. In this year more machinery hours and more diesel consumption are required to collect the kg of fruit produced, and on the contrary the minimum is in year 2 with 1E+08 CTUe.ha^{-1} when less machinery and diesel are required because fruit yield is very low. During the intermediate years the quantification of CTUe.ha^{-1} tends to be stable, and it starts to decrease at years 14-15 when the yield decreases.

Figure 3.3 Evolution of PCR impact values per FU over the years






3.3c) WDP
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
m3·ha-1
6.E-01
5.E-01
4.E-01
3.E-01
2.E-01
1.E-01
0.E+00
m3.kg-1
Year 2
Year 3
Year 4
Year 5
Year 6
Year 7
Year 8
Year 9
Year 10
Year 11
Year 12
Year 13
Year 14
Year 15
Transp.
Material
Machinery
Diesel
Agrochemical
Fertilizers
Electricity
water
m3 kg-1


3.3d) Ecotox
1.E+09
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
CTUe. ha-1
1.E+04
1.E+04
8.E+03
6.E+03
4.E+03
2.E+03
0.E+00
CTUe. kg-1
Year 2
Year 3
Year 4
Year 5
Year 6
Year 7
Year 8
Year 9
Year 10
Year 11
Year 12
Year 13
Year 14
Year 15
Transp.
Material
Electricity
water
Machinery
Fertilizers
Agrochemical
Diesel
CTUe kg-1

3.4. Conclusions

The results of the study reveal that when the FU is related to mass units, using different production scenarios can generate a variation in the environmental impact results of between 7% and 69%, depending on the impact indicator. Therefore, caution should be taken when the FU is related to mass and only a single year is studied, because in the years that the yield is low the impact values per FU increase. On the contrary, in the years that the yield is high, the impact values per FU decrease; thus, depending on the year chosen for the fruit studies, the results can be biased.

Geographic location of fruit orchards is also an important aspect to be considered in the data collection phase, because in temperate areas orchards reach maturity as early as two years after the plantation, and reach full production from the fifth year, which can significantly affect yield average, depending on the amount of years taken into account.

Yield variability not only depends on the orchard age, it also strongly depends on other variables such as fruit variety, geographic location, planting frame, climatic conditions, irrigation system, fertilizers supply and pest control optimization. So it is important, when the FU is related to yield, to have data related to other variables and for many periods of time as possible, to reflect these variables in the results. According to the results obtained in this study in crops with an average life time of twenty years or longer, a multiyear approach is strongly recommended when the functional unit is related to kg produced.

In agricultural stages contribution, fertirrigation has the highest contribution in all impact categories studied, followed by pest management. This is because manufacturing of fertilizers and pesticides have a significant impact. Weed mowing, pruning and harvest impacts are mainly due to the use of machinery, and their involvement in the cultivation process is more sporadic than fertirrigation. As regards initial orchard establishment tasks (soil preparation and planting), if they are not included in the impacts quantification, 5% of total emissions may be overlooked.

Sometimes a lack of data makes it difficult to inventory and include these stages. On the other hand, it is essential to encourage the farmers to try to choose another kind of fertilizer with low environmental impact, and encourage them to try to regulate the application dose, and improve the monitoring of nutrients contents in soil and crop. They should also consider the orchard design and its geographic location to promote a better orchard environmental performance.

This study contributes to complete the fruit LCA literature and provides new information for peach analysis, as well as introducing a multiyear perspective analysis to identify the variability of results related to annual yield conditionings and climatic conditions. The results may be useful to identify the hot spots of peach production, in order to identify the stages with higher impact and obtaining more environmentally friendly fruit practices. The study also provides new inventory data and results on the Mediterranean peach fruit. This work also provides an additional methodological perspective. Although LCA is a useful tool for estimating the impact associated with a product or process, there are still some issues to be resolved regarding to the quality of environmental impact databases and data available because sometimes, due the need to work with generic data, as in the case of pesticides or fertilizers, it may vary the results.

To complete this study, systems boundaries will be further extended to embrace the whole life of peach production, from plant production and plantation to final consumer disposal, in order to estimate the overall impact.

Chapter 4

Photography by Elisabet Vinyes

Life Cycle Assessment of apple and peach production, distribution and consumption, in Mediterranean fruit sector.

Chapter 4. Life Cycle Assessment of apple and peach production, distribution and consumption, in Mediterranean fruit sector.

Based on a manuscript by:
Vinyes, E., L. Asin, S., P. Muñoz, S. Alegre, J. Boschmonart and C.M. Gasol. 2016. Life Cycle Assessment of apple and peach production, distribution and consumption, in Mediterranean fruit sector. *Submitted in April 2016 to Journal of Cleaner Production.*

Abstract

Peach and apple are two important products in the Mediterranean fruit sector. The aim of this work is to analyse environmentally the entire life cycle stages of Mediterranean fruit production, from cradle to grave, considering agricultural, retail, consumption and disposal stages, using a multiyear approach with data from ten years of real production. The results of the study show that, for both fruits, the agricultural stage presents the highest contribution in 13 environmental impact categories, whereas the retail stage makes the highest contribution in 5 impact categories, and the consumption stage has the lowest values in all impact categories. The results related to the carbon footprint calculation show that the retail stage makes a contribution of 39%, the agricultural stage 36%, consumption 24% and disposal 1%. The study also quantified the emissions related to fruit losses during the different stages of the fruit production cycle. Results reveal that the total loss-related emissions are above 10%. This study contributes to completing the fruit LCA literature and provides new environmental information for fruit analysis, introducing the retail, consumption and disposal stages, in order to have a life cycle approach to detect the fruit production hot spots, and to obtain a multiyear perspective analysis to avoid the variability of results related to annual yield and climatic conditions.

4.1. Introduction

In Companies in the food industry are increasingly more interested in reducing the environmental impact associated with their products, in order to provide their consumers with mores sustainable products and better position in the market. According to (Martínez-Blanco et al. 2011) food production has become an important contribution to the depletion of natural resources and climate change. So it is needed that food companies identify the direct and indirect environmental impact (emissions, energy demand, water consumption, resources consumption, waste generation, etc.) of agricultural products and their production processes, in order to develop sustainable management. With the aim of promote sustainable European development, European Commission is encouraging farmers to adopt integrated and organic production practices in order to develop sustainable agriculture (European Commission 2012).

Apple and peach are two important fruit products in the Mediterranean area. According to FAO statistics (2014), Spain is the second (peach and apple) producer in the European Union, producing 1,057,596 tons/year of peach and 532,8174 tons/year for apple. Catalonia is the leading apple production region in Spain (it means 56% of total Spanish apple production) and the second region for peach production (37% of total Spanish peach) (MAGRAMA, 2015).

As report some authors (Vázquez-Rowe et al. 2012; Milà i Canals 2003; Sanyé-Mengual et al. 2013) Life Cycle Assessment (LCA) is one of the most commonly used methodologies to estimate the environmental burdens linked to fruit production. Many of the LCA studies are focused only in cultivation period, so the impacts are partially analysed. This studies do not present enough environmental information regarding to the entire cycle of fruit production excluding initial orchard stages, storing, retail, consumption and disposal (Vinyes et al. 2015). The reason that LCA fruit studies focuses only in cultivation period, is explained because many times there is a lack of inputs data (energy, resources, fuel, etc.) which were not taken in account by farmers years ago.

This study wants to complete the previous publication (Vinyes et al. 2015), which introduced the concept of the multiyear approach (but only for the cultivation stage), presenting an analysis of the remaining stages to complete the fruit cycle: retail, consumption and disposal. The study will also present the carbon footprint values related to fruit production. The fact that it analyses the entire fruit production cycle will provide us with a global vision of this product and detect all the hot spots related to the environmental impact, and enable us to know which parts of the production process it is possible to change in order to promote more sustainable fruit production. The analysis of entire fruit production cycle (orchard establishment, cultivation, retail, consumption, food waste and final disposal), has been possible with the coordination between IRTA, distribution and retail companies as well as other actors involved in fruit sector, which has allowed to work with real and experimental data over a period of 10 years.

4.2. Materials and methods

The environmental analysis of the apple and peach production will be performed using LCA methodology according to ISO Standard 14040:2006, with a multiyear approach considering ten years of real production described by Vinyes(2015).

4.2.1. Life Cycle Assessment approach

LCA According to ISO 14040:2006, LCA analysis evaluates the potential environmental impacts throughout a product's life cycle from cradle-to-grave, including raw material acquisition to production, use and disposal. The characterisation factors used to perform this LCA study are mid-point factors, and the calculation method used is Recipe Midpoint (H). Calculations were performed using Simapro 8 Software, and the ecoinvent database 3.0., and the following environmental impact indicators were considered in the study: Climate Change (CCH), Ozone Depletion (ODP), Terrestrial Acidification (TAC), Freshwater Eutrophication (FEU), Marine eutrophication (MEU), Human toxicity (HTX), Photochemical oxidant formation (PHO), Particulate matter formation (PMT), Terrestrial ecotoxicity (TEC), Freshwater ecotoxicity (FEC), Marine ecotoxicity (MEC), Ionising radiation (IOR), Agricultural land occupation (ALO), Urban land occupation (ULO), Natural land transformation (NLT), Water depletion (WDP), Metal depletion (MDP), Fossil depletion (FDP), Demand for non-renewable energy resources (NRE), Demand Renewable energy (RE).

4.2.2. Functional unit

The ISO 14040:2006 describes the functional unit (FU) as a measure of the function of the system studied and provides a reference to which the inputs and outputs can be related. In this study, in order to compare the results obtained according to yield a variations over the years, a mass-based functional unit was chosen, so the FU for this study is defined as the production of one kg of fruit considering the stages of the whole production cycle: cultivation, distribution, consumption, and final disposal.

4.2.3. Orchard design

Both orchards (apple and peach) studied in this work apply integrated fruit production, and are located in the North West Catalonia region, located in North East Spain. . The apple specie cultivated is *Malus Domestica* with average yield of 48.81 tons/ha. The peach specie cultivated is (*Prunus persica L)* with average yield of the orchard is 36.78 tons/ha.

4.2.3.1. System Boundaries.

Figure 4.1 shows the boundaries of the system analysed and the stages considered. The study considered the entire production cycle, including the following stages: agricultural, retail, consumption and disposal.

a) Agricultural stage

Agricultural stage includes the following tasks: soil preparation and plantation, fertilisation plus irrigation (fertirrigation), pest management, weed mowing, pruning, and harvest. The nursery stage was excluded, mainly due to the lack of reliable data regarding this phase of fruit-growing. For all these tasks, the following inputs were considered: production of fertilisers and their application to the field, pest management substances manufacture and their application (fungicides and insecticides), machinery manufacture and implements used with their transport to the orchard, water use, energy use (from irrigation pumps and input manufacturing).

In order to calculate the environmental impact related to each stage, it is important to know how the tasks are performed and the inputs involved. Soil preparation, plantation tasks, agrochemicals dosage and weed moving were performed mechanically with tractors and their respective implements. Harvesting was carried out manually using an elevation platform to collect the fruit and a tractor to transport the fruit to the storehouse. Fertiliser dosage was applied through the irrigation system with electric pumps (fertirrigation). Pruning was performed manually (wood was crushed and incorporated into the soil).

b) Retail stage

This stage includes the cleaning, packaging and conservation of the fruit in order to be distributed to the market. It also includes the vehicles, diesel, energy, infrastructure used and food waste related to the retail stage.

c) Consumption stage

This stage includes the energy, vehicles, food waste and packaging related to the consumption phase.

d) Disposal stage

This stage considers all the impacts related to final fruit disposal: collection and treatment.

e) Background

This sub-system considers use of: water, materials, resources, energy, infrastructure and other raw materials involved in all the other sub-systems.

4.2.4. Inventory.

Table 4.1 shows the inventory considered in the study for each fruit: apple and peach, according to the FU described in Section 2.2. Experimental data were obtained directly from the Catalan Research Institute of Food and Agriculture Technology (IRTA) orchards, Catalan fruit companies, retail companies and other agents involved. It covers 10 years of real production for apple and peach production and consumption. The inventory was thus elaborated according to the multiyear perspective described in (Vinyes et al. 2015), considering the variation of the annual yield and the climatic conditions.

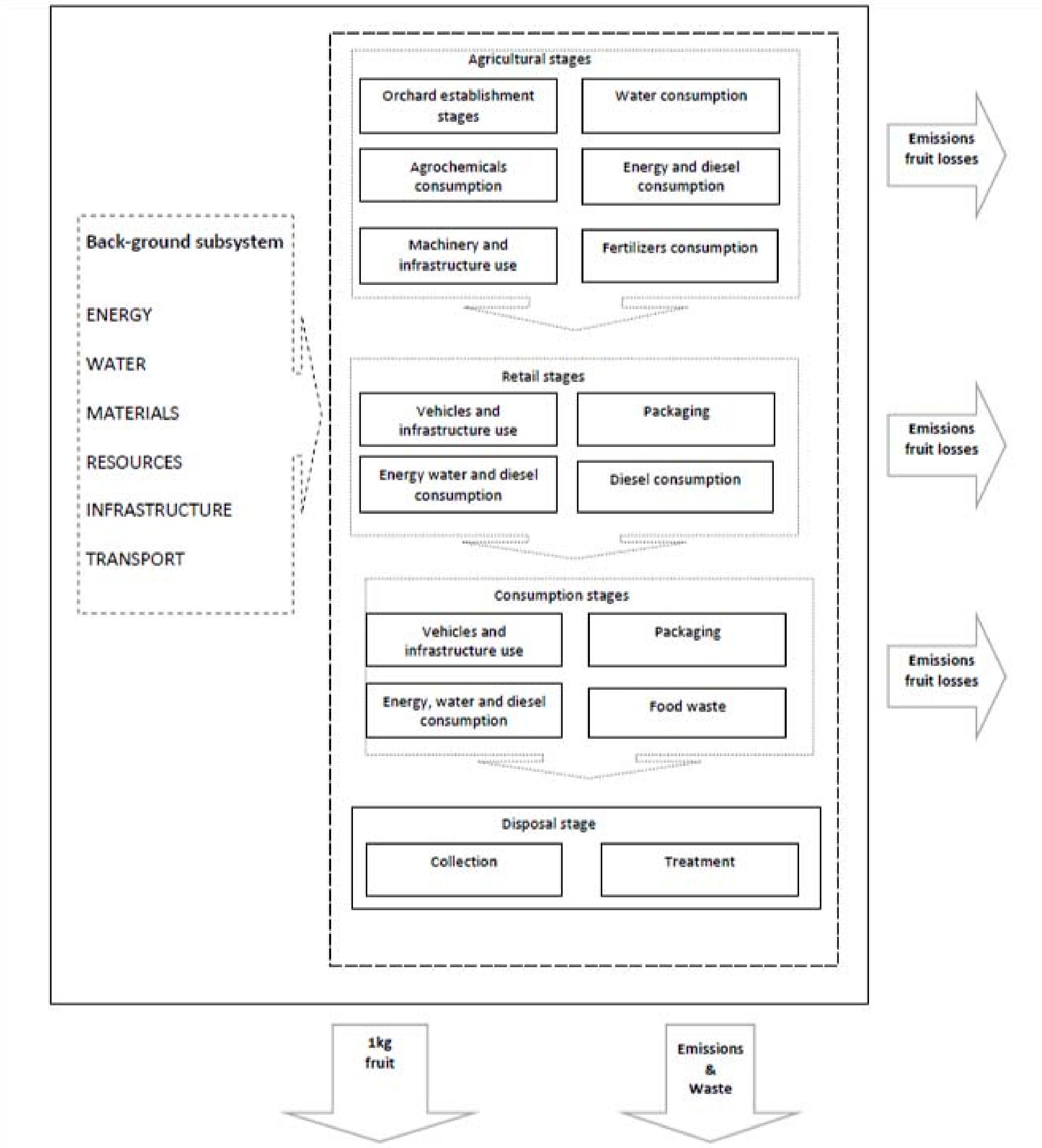


Figure 4.1 Boundaries of the peach system analysed and the stages considered

Table 4.1 Peach inventory inputs according to the FU

Fruit analysed		**Apple**	**Peach**
Agricultural stage	Kg	1.21	1.21
Retail Stage	Kg	1.17	1.17
Consumption	Kg	1	1
Disposal	Kg	0.83	0.83
INPUTS			
Establishment agricultural stages	Units		
Water	l	5.39E-03	4.78E-03
Electricity	kw	1.08E-04	4.78E-05
Diesel	kg	3.38E-04	2.87E-04
Machinery	kg	1.33E-05	1.14E-05
Materials	kg	5.59E-03	5.60E-03
Transport	tkm	8.99E-05	1.19E-04
Cultivation Agricultural stages			
Water	l	2.29E+02	3.39E+02
Electricity	kw	4.99E-02	6.62E-02
Diesel	kg	9.55E-03	9.28E-03
Machinery	kg	6.28E-04	6.04E-04
Fertilizers	kg	6.96E-03	8.85E-03
Agrochemicals	kg	1.42E-03	2.00E-03
Transport	tkm	2.70E-03	3.58E-03
Retail stages			
Water	l	1.71E-01	2.17E-01
Electricity	kw	3.45E-01	4.89E-01
Diesel	kg	1.85E-03	2.45E-03
Materials	kg	2.04E-01	2.63E-01
Transport	tkm	1.57E-02	2.08E-02
Consumption stages			
Water	l	1.04E-04	1.68E-04
Electricity	kw	1.04E-03	1.40E-03
Diesel	kg	4.21E-05	5.65E-05
Materials	kg	5.42E-02	5.42E-02
Transport	tkm	2.10E-01	2.81E-01
Disposal stages			
Water	l	6.64E-06	8.84E-06
Electricity	kw	6.64E-05	7.38E-05
Diesel	kg	2.69E-06	2.97E-06
Transport	tkm	1.35E-02	1.49E-02

4.2.4.1. Data assumptions.

Some assumptions are required to optimise the LCA study and create the inventory. The assumptions related to the cultivation stage were adapted from the previous work of (Vinyes et al. 2015). New assumptions regarding retail and consumption stages were incorporated from information provided by distributors and other agents involved in the entire production chain.

The following assumptions were considered for the agricultural stages:

- **Fertiliser emissions:** diffuse emissions, according to Audsley (1997), they were assumed to be 2% of NH_3 volatilisation for simple nutrient fertiliser (ammonium nitrate), and 4% for multi-nutrient fertiliser (NPK). NO_x emissions were assumed to be 10% of the N_2O emissions. The N_2O emission factor assumed for all fertilisers was 1.25% of N addition according (Brentrup et al. 2001).

- **Change Land Use:** It was assumed that the land occupied is arable and that it had been used for agriculture for a long time. Therefore, no impacts caused by land transformation were taken into account as the plot had been an orchard for more than 25 years (ISO14067).

- **Carbon sequestration:** No specific land and biomass carbon sequestrations were taken into account in this work, as the soil carbon content remained constant during the years of the study, and there was no change in the land use.

- **Agrochemical substances**. It was considered the active ingredients of the pesticides and insecticides, according to the ecoinvent database v3.0 was (ecoinvent Centre).

- **Electricity**: Generation and distribution of electricity demand was estimated using information from the ecoinvent database v3.0, according to the Spanish low voltage electricity mix (ecoinvent Centre).

- **Irrigation water:** The orchard studied was irrigated with electric pumps, and the water came from a Catalan public irrigation canal (Catalonia-Aragon).

- **Machinery:** Machinery production emissions and diesel consumed for machinery operations were also taken from the ecoinvent database v.3.0 (ecoinvent Centre).

- **Transport of input materials and substances to the orchard:** It was assumed that the vehicle used to transport the materials and substances from the production plant to the local point of sale was a 7.5 t lorry, and the distance covered 150km. The vehicle considered to deliver the materials from the regional cooperative to the plantation was a small van<3.5t and the distance, 15km.

The following assumptions were considered for the retail and consumption stages:

-**Transport of fruit**: It was assumed that the local distribution was with a non-refrigerated vehicle, and for national distribution the vehicle was refrigerated. The distance considered was 30 km for local distribution and 800 km for national distribution.

- Packaging materials: Distribution, packaging and commercial packaging were considered. The materials considered were: plastic, plastic film and cardboard and wood. The water used for plastic and cardboard box use was considered (Life Cycle Inventories of Packaging and Graphical Paper. ecoinvent 2007).

- Fruit storage: According to real data collected, the fruit is stored in cold storage chamber after harvest for a period of between 1 and 3 moths while awaiting distribution. In the supermarkets, it is considered that fruit is stored in cold storage chambers for a week, and at consumer's house it is considered that fruit is stored in the fridge for 5 days.

- Fruit losses: According to Food and Agriculture Technology Institute (IRTA) experimental data, the fruit losses during storage phases is quantified as 3%, and the amount of fruit loss during the distribution stage is 15%. According to (WRAP 2008), fruit waste at houses is quantified as 17%.

4.3. Results and discussion.

Results and discussion are organised into 4 sections: 4.3.1) LCA results, 4.3.2) PCR indicators, 4.3.3) Carbon footprint results and 4.3.4) Fruit loss emissions

4.3.1. LCA results

Table 4.2 and Table 4.3 show the results of the multiyear LCA for apple and peach production, distinguishing the impact for the following stages: agricultural, retail, consumption and disposal. The tables also show the percentage contribution of each stage. For both fruits, agricultural stages (including establishment and cultivation) present the highest contribution in the following impact categories: TAC, FEU, MEU, HTX, PHO, PMT, TEC FEC MEC, IOR, ULO, WDP, MDP, FDP, RE, mainly due to fertiliser production, machinery use in the field and diesel consumption. The retail stage makes the highest contribution in the remaining impact categories: CCH, ODP, ALO, NLT, NRE, due to diesel use related to the fruit transport, and also to the energy consumed to conserve the fruit in the storage centres. Consumption and disposal stages make no high contribution in any impact category except for CCH. The consumption stage contribution is lower in all impact categories because this stage is very short, taking between 1 and 5 days, and no production processes are involved, except for domestic transport between shops and houses, and the electricity consumption of the freezer. The disposal impact contribution is also low because fruit waste is collected with other municipal waste and its impact is shared. Results obtained are coherent with other fruit studies: Alaphilippe et al., 2013; A. Cerutti et al., 2011; Clasadonte et al., 2009; Coltro et al., 2009; Ingwersen, 2012; Milà i Canals et al., 2006; Mithraratne et al., 2008; Ridoutt et al., 2010. Even so, only a few of these studies include the impact of the supply and consumption phase: Milà i Canals et al., 2006; A. Cerutti et al., 2011.

Table 4.2 Multiyear LCA apple results

Indicator	Units	Total	Agricultural %	Retail %	Consumption %	Disposal %
CCH	kg $CO_{2\ eq}$	3.02E-01	36.86	38.82	22.86	1.46
ODP	kg CFC-11 $_{eq}$	1.79E-01	32.53	67.16	0.29	0.02
TAC	kg $SO_{2\ eq}$	3.76E-02	93.65	5.69	0.62	0.04
FEU	kg P $_{eq}$	1.05E+01	83.95	15.66	0.36	0.02
MEU	kg N $_{eq}$	1.67E-03	88.86	8.54	2.44	0.16
HTX	kg 1,4-DB $_{eq}$	8.52E-01	84.81	12.23	2.78	0.18
PHO	kg NMVOC	1.72E-02	91.85	6.90	1.18	0.08
PMT	kg PM10 $_{eq}$	9.23E-03	91.56	7.30	1.07	0.07
TEC	kg 1,4-DB $_{eq}$	3.36E-04	80.46	15.99	3.34	0.21
FEC	kg 1,4-DB $_{eq}$	4.72E-02	86.39	5.18	7.92	0.51
MEC	kg 1,4-DB $_{eq}$	4.36E-02	86.52	5.55	7.46	0.48
IOR	kBq U235 $_{eq}$	3.84E-01	68.37	29.76	1.75	0.11
ALO	m^2a	4.10E-01	20.10	61.65	17.15	1.10
ULO	m^2a	5.00E-02	88.21	7.03	4.47	0.29
NLT	m^2	3.33E+02	12.62	87.10	0.26	0.02
WDP	m^3	2.17E-01	99.31	0.66	0.03	0.002
MDP	kg Fe $_{eq}$	1.98E-01	88.95	6.45	4.32	0.28
FDP	kg oil $_{eq}$	1.39E+05	83.95	15.66	0.36	0.02
NRE	MJ-$_{Eq}$	4.14E+07	14.55	85.18	0.26	0.02
RE	MJ-$_{Eq}$	2.12E+05	99.95	0.01	0.04	0.003

Table 4.3 Multiyear LCA peach results

Indicator	Units	Total	Agricultural	Retail	Consumption	Disposal
			%	%	%	%
CCH	kg $CO_{2\ eq}$	3.81E-01	36.38	38.70	23.67	1.25
ODP	kg CFC-11 $_{eq}$	2.33E-01	26.71	72.98	0.30	0.02
TAC	kg $SO_{2\ eq}$	4.74E-02	93.14	6.20	0.63	0.03
FEU	kg P $_{eq}$	1.08E+01	79.21	20.29	0.47	0.02
MEU	kg N $_{eq}$	2.14E-03	88.78	8.61	2.48	0.13
HTX	kg 1,4-DB $_{eq}$	1.10E+00	83.84	13.18	2.83	0.15
PHO	kg NMVOC	2.20E-02	91.43	7.33	1.18	0.06
PMT	kg PM10 $_{eq}$	1.17E-02	90.99	7.87	1.08	0.06
TEC	kg 1,4-DB $_{eq}$	4.34E-04	79.79	16.74	3.30	0.17
FEC	kg 1,4-DB $_{eq}$	6.20E-02	86.23	5.33	8.02	0.42
MEC	kg 1,4-DB $_{eq}$	5.71E-02	86.29	5.75	7.57	0.40
IOR	kBq U235 $_{eq}$	5.10E-01	66.73	31.48	1.70	0.09
ALO	m^2a	5.08E-01	20.75	64.45	14.05	0.74
ULO	m^2a	6.44E-02	88.20	7.19	4.38	0.23
NLT	m^2	4.68E+02	11.89	87.84	0.25	0.01
WDP	m^3	3.21E-01	99.35	0.62	0.03	0.001
MDP	kg Fe $_{eq}$	2.36E-01	87.56	7.37	4.81	0.25
FDP	kg oil $_{eq}$	1.42E+05	79.21	20.29	0.47	0.02
NRE	MJ-$_{Eq}$	5.79E+07	13.41	86.33	0.25	0.01
RE	MJ-$_{Eq}$	2.69E+05	99.94	0.01	0.04	0.002

4.3.2. PCR Indicators

Figure 4.2 presents the contribution of each stage considered (agricultural, retail, consumption and disposal) according to the indicators described by Fruits and nuts PCR (Environdec), in order to obtain verified and comparable information. In both fruits, it can be observed that the agricultural stage makes the highest contribution in HTX and WDP indicators, and the retail stage presents the highest contribution in CCH and NRE indicators. In CCH indicator, the main contributor is retail followed by agricultural stage, consumption and disposal for both fruits. In the agricultural stages, the CCH impact is related to emissions of fertiliser production and diesel consumed by machinery used in the orchard tasks. For the retail stages, the CCH impact is due to the diesel consumed by distribution vehicles and the energy used for cold storage chambers. With the WDP indicator, 99% of the impact is in the agricultural stage due to the amount of water used in the irrigation operations and fertiliser production. With the HTX indicator, 85% of the impact is located in the agricultural stage due to the use of fertilisers and agrochemical substances and their production. In NRE, 85% of the impact is related to the energy used to cool the fruit and keep it in good condition before being sold.

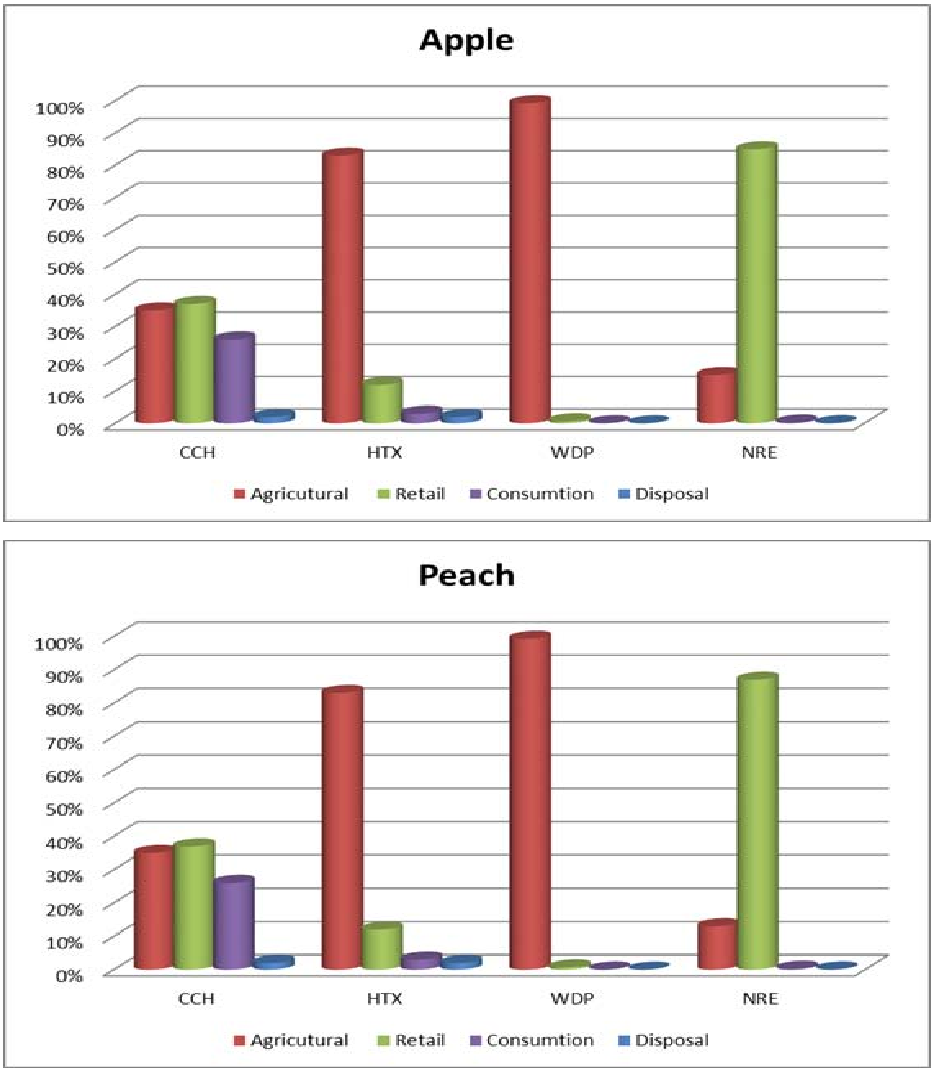


Figure 4.2 Impact contribution of PCR indicators for apple and peach production

4.3.3. Carbon footprint results

Here we present the results obtained for the CHC indicator in relation to the stages studied and the inputs considered in order to detect hot points of CO_2 emissions. The carbon footprint value for apple is 0.302 kg $CO_{2\ eq.}$ and for peach 0.381 kg $CO_{2\ eq.}$. Figure 4.3 presents the percentage of emissions contribution related to each production stage considered in the study for apple and peach. It can be observed that retail has a contribution of 39%, the agricultural stage 36-37%, consumption 23-24% and disposal 1%. In the agricultural stage, the main impact related to emissions is due to the fertilisers and agrochemicals production. In the retail stage, the main impact is due to the diesel consumption for transport and the energy consumed by the refrigerator chambers. In the consumption stage, the impact is explained by the production of the packaging material involved and energy consumption of the shop coolers. For disposal, the impact is related to collection of fruit waste and its composting treatment.

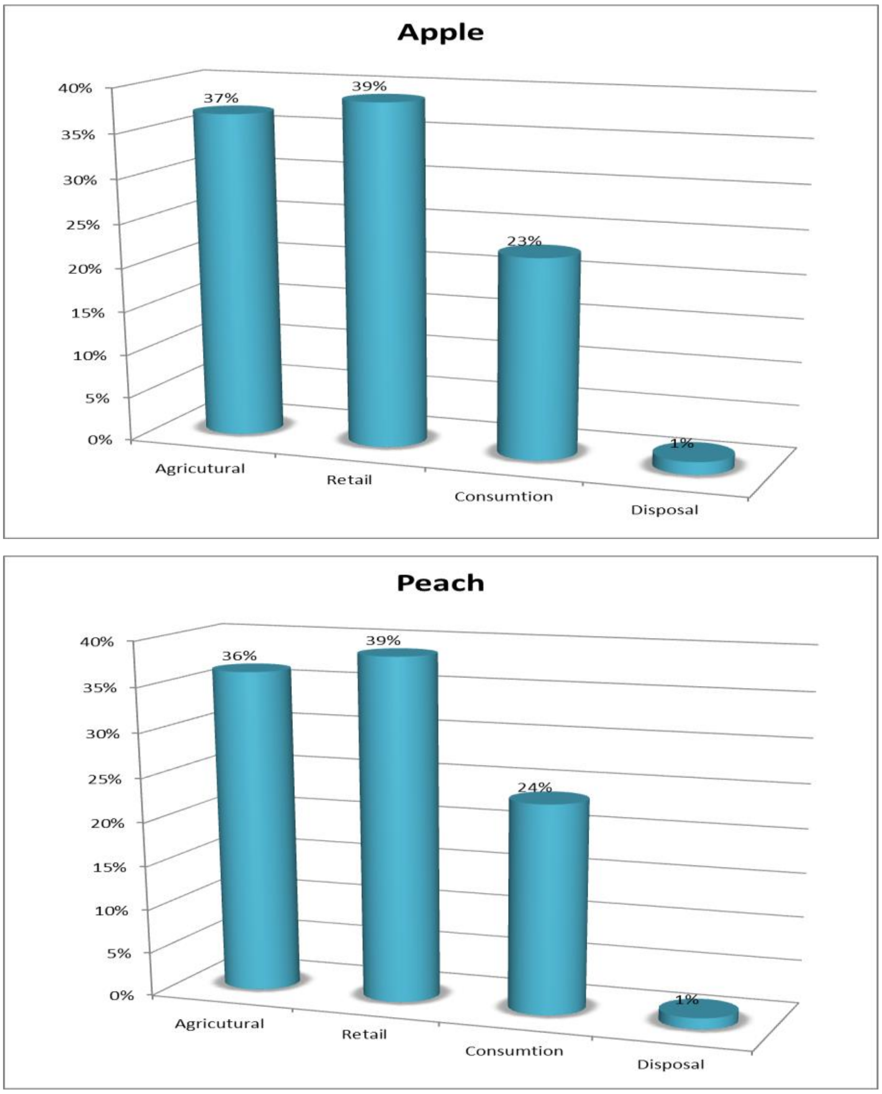


Figure 4.3 Contribution percentages in CO_{2eq} emissions of the production stages considered

4.3.4. Fruit losses emissions

Figure 4.4 shows the percentage of fruit losses for each stage, and the emissions related according to the FU (1kg of fruit). According to Institute IRTA experimental data, the fruit losses during agricultural stage is quantified as 3%, and the amount of fruit loss during retail stage is 15%. Fruit waste/losses at houses are quantified as 17%. The high losses during the consumer stage can be explained because consumers do not properly plan their weekly shopping and buy excess fruit, then do not manage to eat all the fruit they buy on time and the fruit becomes damaged. Another explanation is that consumers do not properly store the fruit that they buy and the fruit rots before it is eaten. Fruit losses during the retail stage is explained because it is easy to break the cold chain their manipulation during distribution, or the fruit can receive an impact that causes its degradation before arriving at the selling points. According to figure 4.4, considering the fruit losses for each stage involved, a 1.21 kg of fruit must be produced in agricultural stage because 1kg of fruit arrives to the market what means and increase of 10%. At last only 0.83 kg of fruit is consumed at houses due to food waste. Total emissions related to losses during apple and peach production is quantified 0.034 $kgCO_{2eq}$.

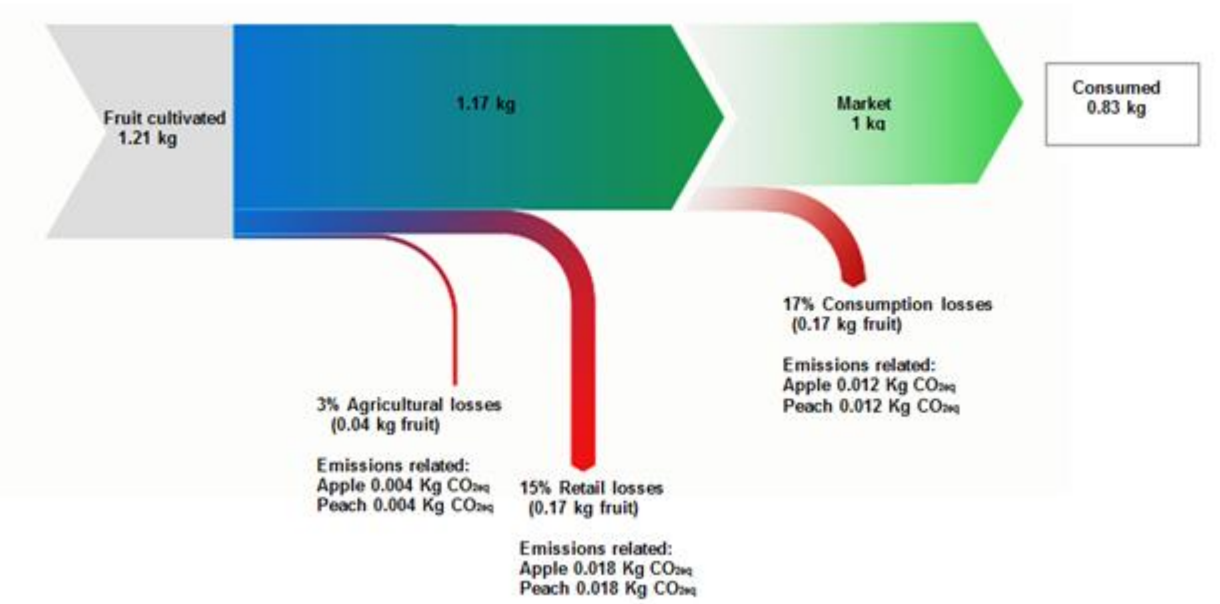


Figure 4.4 Percentage of fruit losses for each stage, and the emissions for apple and peach

4.4. Conclusions

The results of the study show that, for both fruits (apple and peach), the agricultural stage presents the highest contribution in 13 environmental impact categories, whereas the retail stage makes the highest contribution in 5 impact categories. The consumption and disposal stages make the lowest contribution in any impact category, and therefore the main environmental impact is found in the agricultural and retail stages. Consequently, further research is needed in order to improve agricultural practices and adopt more sustainable practices and reduce the environmental impact.

Referring to the indicators defined by Fruits and nuts PCR, in both fruits the agricultural stage makes the highest contribution in the Human Toxicity and Water Depletion indicators, and the retail stage makes the highest contribution in the Climate Change and Non-renewable Energy indicators. The results related to the carbon footprint indicator show that the retail stage makes a contribution in total emissions of 39%, the agricultural stage 36%, the consumption stage 24% and disposal 1%. The study also quantified the emissions related to fruit losses during the entire fruit production cycle, and the results quantify these losses as above 10% of the total emissions for both fruits.

According to Institute IRTA experimental data, the fruit losses during agricultural stage is quantified as 3%, and the amount of fruit loss during retail stage is 15%. Fruit waste/losses at houses are quantified as 17%. Considering the fruit losses for each stage involved, agricultural production must be increased a 10% because 1kg of fruit arrives to the market, at last only 0.83 kg of fruit is consumed at houses due to food waste. Further research is needed to avoid fruit losses in different stages, especially the retail stage where the losses are the highest. It is important to train all the actors involved in the retail stages and consumers at home that they need to change certain behaviours to avoid losses and food waste, and especially in the current context of global warming and resource depletion it is necessary to promote more sustainable consumption.

This study contributes to completing the existing fruit LCA literature. Besides considering the agricultural stage, it includes the retail, consumption and disposal stages, also provides new environmental information for fruit production analysis. Furthermore, it introduces analysis according to the variability of results related to annual yield, geographic and climatic conditions, agricultural practices and also consumer style. Many of the studies published only consider the agricultural stage and have no information related to the retail and consumption stages, they moreover mainly focus on one productive year, while the life span of fruit plantations can be longer than 10-15 years (depending on the fruit), so the fact of only considers one productive year it can therefore generate variations in the results depending on the annual yield.

PART III

WATER FOOTPRINT OF FRUIT PRODUCTION.

Chapter 5

Photography by Elisabet Vinyes

Water footprint of Mediterranean fruit production: a case study of Spanish apple and peach

Chapter 5. Calculation of water footprint of fruit production.

Based on a manuscript by:

Vinyes, E., P. Muñoz, L. Asin, S. Alegre, and C.M. Gasol. 2016. Water Footprint of Mediterranean Fruit Production: A Case Study of Spanish Apple and Peach. Submitted in May 2016 to Journal of Industrial Ecology.

Abstract

Agricultural products are great consumers of water resources. Given that peach and apple are two important products in the Mediterranean fruit sector, this study will analyse the water footprint related to fruit production combining two existing water footprint approaches: ISO 14046 Specifications with Life Cycle Approach and FAO guidelines. The study will be performed using multiyear data for a period of 9 years of real production and considering agricultural, retail, consumption and disposal phases. The results obtained reveal that, with the FAO approach, the water footprint is 575m^3/t for apple production and 681 m^3/t for peach. On the other hand, with the ISO approach, the water footprint is 520 m^3/t for apple production and 647 m^3/t for peach. With both approaches, agricultural production accounted for 92.94% of the total water footprint in both fruits, followed by the retail stage, 4-6%, and consumption stage, 1-2% m3/ton. It is observed that, for the entire fruit production cycle, direct water accounted for 62-29% and indirect water for 31-38%. In terms of quality data, the results obtained also demonstrate that, when the quantified indicator is linked to mass unit or yield, the multiyear approach is important, in order to cover the variability of local climatic conditions (precipitations) and management input operations and water resources. Deficit irrigation strategies play an important role in farm-level water management strategies in order to optimize water use efficiency in agriculture. Despite the methodological differences detected between FAO guidelines and LCA approaches, it seems that both methods are suitable for water consumption accounting; it depends on the background and the boundaries of the studies as well as the quality of the data available.

5.1. Introduction

Nowadays, the interest of the agrifood sector in analysing the environmental impacts of its products throughout its supply chain has increased considerably. Food companies have used environmental indicators such as Carbon Footprint (CF), Cumulative Energy Demand (CED), Water Footprint (WF) and Life Cycle Assessment (LCA) as Product Environmental Footprint (PEF) (Manfredi et al. 2012) to quantify the environmental performance of their agrifood products and reduce their impact related to the ingredients of their supply chain. The CF has been one of the most studied and analysed, because it focuses on climate change impact (Vinyes et al. 2015; Martínez-Blanco et al. 2011; Milà et al. 2007). People use a great deal of water for daily activities, but most consumption of water resources is linked to the production of goods and services such as food, paper, cotton clothes, etc. According to Chapagain (2006), the interest in the WF arises from the recognition that human impacts on water systems may be related to human consumption, and that issues such as water scarcity or pollution can be better understood and managed considering production and retailers in their entirety. Recently (in 2014), the ISO published a reliable methodological framework to calculate the Water Footprint with a life cycle approach. The environmental focus of water footprinting is defined by ISO 14046 as "the potential environmental impacts related to water associated with a product, process or organisation".

Quantifying the WF of a good or service can be useful information for consumers, retailers, traders and other agents that play an important role in supply, particularly of goods that are water intensive, like food items, beverages, and textile materials (Canals et al. 2010). In water-scarce areas, knowing the WF of a good or service can be useful to determine how to make best use of the scarce water available (Aldaya and Hoekstra 2010). From a strategic sourcing perspective, it is important to better understand water requirements of crops in order to determine areas best suited to production, particularly given predicted changes in rainfall and water availability as a result of global climate change. Water resource use in agriculture is generally quantified in relation to yield obtained during the harvest (Aldaya and Hoekstra 2010). WFs have been calculated for a wide range of agricultural products, but not considering the life cycle approach: cotton in India (Chapagain et al. 2006) tea and coffee in India (Chapagain and Hoekstra 2011), meat products (Ercin et al. 2012), Australian Mango (Ridoutt et al. 2010), Italian wine (Lamastra et al. 2014) and Spanish tomatoes (Chapagain and Orr 2009). Agricultural products are a way of moving and exporting water from agricultural production to consumer areas (Chapagain et al. 2006).

According to (Chapagain and Hoekstra 2004), in Spain agricultural products consume around 80% of water resources, followed at a distance by industrial consumption with 15% and domestic consumption 5%. As stated by (Aldaya and Hoekstra 2010), fresh fruit represents 2.9% of Spanish crop water use. This is in a context where water resources are unevenly distributed and, in regions where flood and drought risks are increasing, improved water management is urgently needed (Salmoral et al. 2011). Some authors (Milà i Canals et al. 2009; Pfister et al. 2009; González 2011; Núñez et al. 2013; Ferrandis 2015) take into account the globally unequal distribution of freshwater resources and the importance of knowing local data.

Peach and apple are two important products in the Mediterranean fruit sector (Vinyes et al. 2015). According to FAO (2013) statistics, Spain is the second peach and apple producer in the European Union with 1,129,300 tons/year of peach and 962,000 tons/year of apple. Catalonia (North East Spain) is the first apple production region in Spain (54% of total Spanish apple production) and the second region for peach production (35% of total Spanish peach (MAGRAMA 2013). Considering that apple and peach production carried out in Spain is located in the Catalonia region, and that both fruits represent production of 70% of Spanish fruit (MAGRAMA 2013), this study aims to analyse the water footprint for apple and peach production in the region of Catalonia (North East Spain) over a period of nine years (multiyear perspective), using real data and with real information about Kc coefficient and Evapotranspiration (ETc) values, in order to provide useful information to help producers understand water requirements of crops and also introduce new opportunities for water efficiency alternatives, without significantly affecting the yield.

A variety of methodologies have been published for water footprinting calculations, using different forms of water use and creating confusion in the results. As (Ridoutt et al. 2010) report, most water footprints are the crude summation of more than one form of water consumption (blue, green and grey water) from locations that differ in terms of water scarcity. As such, water footprints of different products are not comparable. Several authors have raised significant concerns with respect to the concept and its usefulness, as it does not provide sufficient information on the opportunity cost of water, and as an indicator of sustainability and environmental impact (Čuček et al. 2012; Chenoweth et al. 2013; Perry 2014; Gu et al. 2014; Wichelns 2010). To calculate the WF, Standard ISO14046:2015 will be used and will be complemented with the FAO guidelines for a dual purpose: to detect the regional differences generated by Evapotranspiration (ETc) and to demonstrate the huge variability that can by generated by the various methods existing.

5.2. Method and data

This study will calculate the WF of fruit production (apple and peach) in Spain using Standard ISO14046:2015 (Ferrandis 2015), complemented with FAO guidelines, in order to quantify water consumption associated (directly and indirectly) with these products and the potential impacts of water use and associated pollution, as well as to detect the regional differences related to climate variations and crop evapotranspiration requirements.

5.2.1. Water footprint Life Cycle approach (ISO14046:2015).

The new ISO 14046:2014 “Environmental Management. Water Footprint. A principle, Requirements and Guidelines”, is international water footprinting guidance Standard and forms part of the ISO 14000 series of environmental management standards. ISO 14046 is designed to assess and report the potential impacts of water use and pollution of products and processes, based on the Life Cycle Assessment (LCA) perspective, which incorporates an inventory of input/output data, and an assessment of the data to understand the environmental significance of the results. A water impact category is thus defined as a class representing environmental issues of concern to which the life cycle inventory analysis results may be assigned.

According to ISO 14046, requirements for water footprinting assessments should include: potential environmental impacts related to water, relevant geographical and temporal dimensions, quantity of water use and changes to water quality and information about local hydrology. The process can be modular, where the water footprint of different life cycle stages can be summed to represent the water footprint, provided that these are clearly defined and explained. Water issues in LCA and water footprinting can be separated into quantitative (water scarcity) and degradative (pollution) concerns (Pfister et al. 2015).

In section 5.3.2 of the ISO 14046 Standard (“Elementary Flows”), the flows which WF should include are defined:

- Quantities of water used
- Resource types of water used, such as precipitation, surface water, groundwater, etc.
- Water quality parameters and/or characteristics, such as physical, chemical, and biological characteristics
- Forms of water use, such as evaporation, transpiration, product integration, release into different drainage basins, in-stream use, etc.
- Geographical location of water withdrawal, including information on the physical location of water withdrawal
- Temporal aspects of water use, such as time of use and release
- Emissions to air, water and soil with impact on water quality.

5.2.1.1. LCA analysis

In order to calculate the WF according to ISO 14046:2015 specifications, the inventory data have been elaborated from the LCI perspective in accordance with ISO 14040:2006 (Environmental management - Life cycle assessment - Principles and framework) and performing the allocations explained in section 5.2.4.2 of this chapter.

The LCA perspective aims to quantify impacts on water consumption. Therefore, to perform the LCA study, Simapro 8 software was used, combined with CROPWAT software (FAO Organization). The inventory considered direct water (inputs and outputs resulting from an organization’s direct activities: irrigation, agricultural tasks, cleaning, storing) and indirect water (inputs and outputs which are consequences of an organization's activities but which arise from processes controlled by other organizations: production and processing of raw materials, transport of materials, fertilizer and pesticide manufacturing, waste management, use, production of auxiliary materials and energy carriers and use, packaging and machinery production, product use).

To quantify the indirect water impact Simaparo 8 software was used, according to the ecoinvent v3 database, and the Water Scarcity characterization method defined by Hoekstra et al. 2012. Results of water scarcity impact are presented in m^3 according to the Water Scarcity Indicator (WSI), which is based on a consumption-to-availability ratio calculated as the fraction between consumed (referred to as blue water footprint) and available water. The latter considers all runoff water, of which 80% is subtracted to account for environmental water needs. The indicator is applied to the consumed water volume and only assesses consumptive water use, but needs to be adapted in some cases because some outlying regions are not covered.

Direct water impact has been calculated using the volume of blue water obtained in CROPWAT software, adapted to Spain's water availability, according to the Water Stress index described by (Nunez et al. 2015) for the River Ebro basin in Spain, suggesting a WSI value of 0.26.

Although ISO specifications recommend that precipitation water (green water) it should be included in the WF inventory, it is difficult to resolve its impact. The green water footprint measures the part of the evaporated rainwater that has been appropriated for the production of the products and is not therefore available for nature. According to Milà i Canals et al., 2009; Jefferies et al. 2012, green water consumption by the product system does not generally introduce significant changes in the local environment. Consequently, green water is generally excluded from the impact assessment phase in LCA. Thus, in this study the green water impact has not been included in the ISO results.

5.2.2. Water footprint FAO Guidelines approach

With the FAO WF approach, the water consumption related to a product or process is analysed. Three colour components are distinguished: green, blue and grey (Chapagain and Hoekstra 2004). The green component refers to rainwater stored in the soil. The blue component refers to surface and groundwater, and the grey water component is defined as the volume of freshwater required assimilating the pollutant load based on existing ambient water quality standards.

According to (Chapagain and Hoekstra 2004) specifications, green water was estimated as the ratio of green water use (m^3/ha) to fruit yield (ton/ha), where total green water use is obtained by summing up green water evapotranspiration over the growing period (green water evapotranspiration was calculated with a time step of 5 days, as the minimum effective rainfall and crop water requirement). Blue water was considered to be equal to the ratio of the volume of irrigation water used to the crop yield. Grey water was calculated as the pollutant load that enters the water system divided by the maximum acceptable concentration for the pollutant considered (kg/m^3) and the crop production (ton/yr).

5.2.2.1. FAO WF analysis

In our study, to calculate the WF consumption according to FAO Guidelines, CROPWAT software was used for direct water combined with the database ecoinvent v3 for indirect water. In this work, to calculate the green and blue water of fruit production, CROPWAT software was used, applying the irrigation schedule option (fixed interval per stage and fixed application depth), which includes soil water balance and tracks the soil moisture content. A field efficiency of 0.9 was assumed for drip systems according to (Allen et al. 1998). Blue water accounting obtained with CROPWAT was considered as direct water, and this value was complemented with the amount of blue indirect water consumed for secondary processes according to ecoinvent3 database values.

The total crop water requirement, effective rainfall and irrigation requirements were estimated using the CROPWAT software, using experimental ETc values from IRTA orchards (Marfà et al. 2000; Lopez et al. 2011; Girona et al. 2003). Climate data were taken from the METEOCAT (Catalan Meteorology Service) database for stations located in the municipality where the fruit orchards were located, for the years 2000-2009. Crop parameters (crop coefficients, planting and harvesting date) were taken from experimental orchards from the Catalan Research Institute of Food and Agriculture Technology (IRTA). Soil types and average crop yield data were obtained directly from the IRTA experimental orchards. Soil classification was performed according to USDA soil taxonomy classifications (Natural Resources Conservation Service 1999).

Regarding the grey component, for fruit cultivation the approach was to account for water pollution as a result of the use of nitrogen fertilizer. The grey water required per ton of N was calculated considering the volume of nitrogen leached (ton/ton) and the maximum allowable concentration in the ambient water system (Chapagain and Hoekstra 2004). The quantity of nitrogen that reaches ground or surface water was assumed to be 10% of the applied fertilization rate (in kg/ha/yr) (Chapagain and Hoekstra 2007). The nitrate concentration recommended by the European Nitrates and Groundwater Directives for nitrate in water is 50 mg/l, measured as NO_3 according to (European Commission Directive 1991:2006). The natural concentration of pollutants in the receiving water body was assumed to be negligible. The consequence of the use of other substances, such as pesticides and herbicides, was not evaluated.

5.2.3. System description.

According to Figure 5.1 the study includes all the phases involved in fruit production: farming, retail and consumption. In both cases, apple and peach, 9 years of real production were considered. The study includes the cultivation period, as well as the impact of the initial orchard establishment tasks (soil preparation and planting). The retail stage considered the water related to local distribution. The water use related to fruit losses during the supply chain and food waste was also considered.

5.2.3.1. Experimental orchards design.

With both fruits, cultivation is undertaken using integrated fruit production according to (Morris and Winter 1999). Integrated Production is defined as systems of agricultural production of quality food, using methods that respect the environment and human health in order to obtain high-quality products, minimizing the use of agrochemicals. The two orchards chosen are in nearby areas, but are geographically separated by a distance of 50 km, although the climatic conditions are similar.

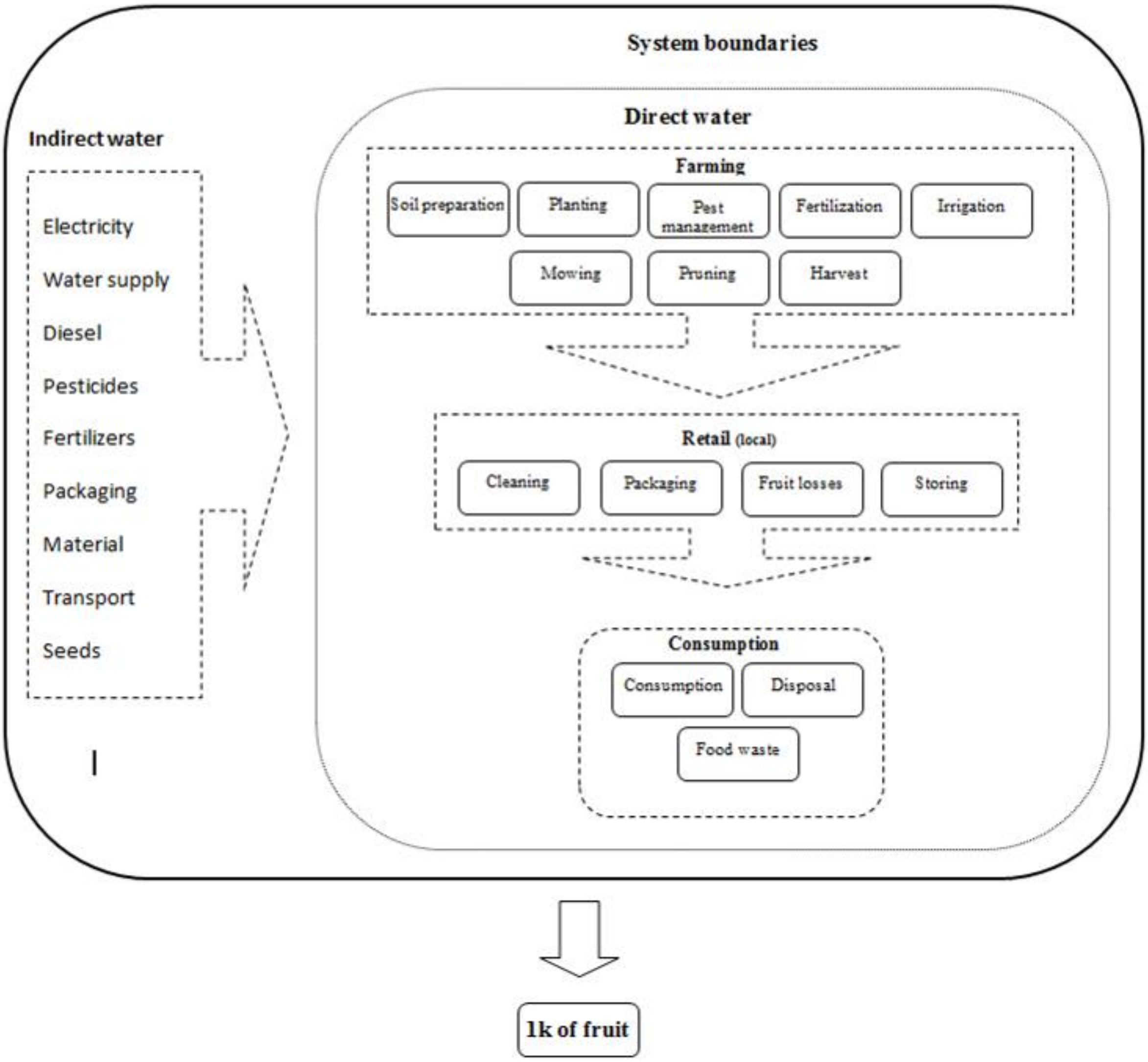


Figure 5.1 System boundaries from cradle to grave for apple and peach production

5.2.3.1.1. Case study 1: Apple

The system studied is an apple orchard *(Malus domestica.)* located in Catalonia (North East Spain), in a town called El Poal. It covers an area of 1.5 hectares, and is cultivated using integrated agricultural practices according to the specifications of European Commission Directive 1991:2006). According to USDA, the soil texture is clay-loamy, and its physical proprieties are favourable for fruit cultivation. The annual average temperature in the Poal area is 14.8ºC, the minimum is -8.1ºC and the maximum 38.4ºC. The annual average rainfall is 372 mm. The annual average production is 43.35 tons/year.

5.2.3.1.2. Case study 2: Peach

The system studied is a peach orchard *(Prunus persica L.)* located in Catalonia (North East Spain) in a town called Gimenells. It covers an area of 1 hectare and is cultivated using integrated agricultural practices. According to USDA, the soil texture is loamy, and its physical proprieties are favourable for root development, with fruit cultivation being possible. The annual average temperature in the Gimenells area is 14.2ºC, the minimum is -10.1ºC and the maximum 39.2ºC. The annual average rainfall is 350 mm. The annual average production is 33.70 tons/year.

5.2.4. Inventory.

Experimental data were obtained directly from the Catalan Research Institute of Food and Agriculture Technology (IRTA) orchards and retail enterprises, to make the inventory cover 9 years of real production. Some allocations were needed to work with the data. Table 5.1 shows the inventory considered in the study, according to the FU described in section 2.4.1.

5.2.4.1. Functional unit.

According to ISO 14046, WF results must be linked to a Functional Unit (FU). The FU is a measure of the function of the system studied and provides a reference to which the inputs and outputs are related. According to the characteristics of the study and the purpose, the FU chosen was defined as a “cultivation of 1 kg of fruit”. Considering that the function of the orchard is to produce, the fact of using an FU based on a mass unit also allows seasonal variability to be reflected. A functional unit based on hectares could hide the variability of results (Canals et al. 2010).

Table 5.1 Summary of the inventory for apple and peach production according to the FU

STAGES	**Apple**	**Peach**	**Units**
1.INITIAL STAGES			
1.1 Soil Preparation			
Water consumption	1,E-03	2,E-03	litres
Electricity consumption	0,E+00	0,E+00	kw
Diesel consumption	1,E-04	1,E-04	kg
Machinery use	4,E-06	5,E-06	kg
1.2 Planting			
water consumption	3,E-03	2,E-03	litres
Electricity consumption	7,E-05	0,E+00	kw
Diesel consumption	2,E-04	1,E-04	kg
Machinery	6,E-06	4,E-06	kg
Orchard materials			
Wood	2,E-03	2,E-03	kg
Iron	2,E-03	2,E-03	kg
PVC	4,E-04	5,E-04	kg
2.CULTIVATION			
2.1 Fertilization			
Water consumption	3,E-02	4,E-02	litres
Electricity consumption	3,E-02	4,E-02	kw
Diesel consumption	0,E+00	0,E+00	kg
Machinery	0,E+00	0,E+00	kg
Fertilizers			
N	2,E-03	3,E-03	kg
K_2O	2,E-03	3,E-03	kg
P_2O_5	3,E-04	4,E-04	kg
Fe	9,E-06	1,E-05	kg
2,2 Irrigation			
Water irrigation	2,E+02	3,E+02	0
Electricity	5,E-03	7,E-03	0
2.3 Pest management			
Water consumption	4,E-02	6,E-02	litres
Electricity consumption	2,E-03	3,E-03	kw
Diesel consumption	2,E-03	2,E-03	kg
Machinery	1,E-04	1,E-04	kg
Agrochemical substances			
Fungicides	9,E-04	1,E-03	kg
Herbicides	2,E-04	3,E-04	kg
2.4 Pruning			
Water consumption	0,E+00	0,E+00	litres
Electricity consumption	2,E-05	0,E+00	kw
Diesel consumption	1,E-03	1,E-03	kg
Machinery	7,E-05	7,E-05	kg
2**.5 Moving**			
Water consumption	0,E+00	0,E+00	litres
Electricity consumption	0,E+00	0,E+00	kw
Diesel consumption	1,E-03	1,E-03	kg
Machinery	6,E-05	8,E-05	kg

2.6 Harvest			
Diesel consumption	3,E-03	3,E-03	kg
Machinery	2,E-04	2,E-04	kg
3.RETAIL			
3.1 Storing and preparing			
Water consumption	1,E-01	2,E-01	litres
Electricity Freezer	2,E-01	4,E-01	kw
Diesel consumption	0,E+00	0,E+00	kg
Machinery	0,E+00	0,E+00	kg
Packaging			
Plastic	7,E-03	8,E-03	kg
wood	1,E-01	2,E-01	kg
Cardboard	2,E-02	3,E-02	kg
Film	2,E-03	2,E-03	kg
3.2 Distribution			
Van	2,E-03	3,E-03	tkm
Lorry	1,E-02	1,E-02	tkm
Others	0,E+00	0,E+00	tkm
Diesel	1,E-03	2,E-03	kg
Electricity freezer	2,E-02	3,E-02	kw
Water	5,E-03	7,E-03	litres
Packaging			
Plastic	4,E-04	5,E-04	kg
wood	2,E-03	3,E-03	kg
Cardboard	1,E-03	1,E-03	kg
Film	2,E-04	2,E-04	kg
4. COMSUMPTION			
Vehicle	Amount FU	Amount FU	Units
Car	2,E-01	3,E-01	tkm
Moto	1,E-03	1,E-03	tkm
Diesel	4,E-05	5,E-05	kg
Electricity	1,E-03	1,E-03	kw
Water	1,E-04	2,E-04	litres
Fruit loses	5,E-02	5,E-02	kg

5.2.4.2. Data assumptions.

In order to complete the WF study and create the inventory, certain assumptions were made according to the literature and the data available.

- **Irrigation system**: In both cases the irrigation system for the fruit orchards is the drip system with an efficiency of 85% (Allen et al. 1998). We considered average water network losses of 22% of distribution according to (Canals et al. 2010) for the case of Spanish broccoli.
- **Irrigation water:** The orchard studied was irrigated with electric pumps, and the water came from a Catalan public irrigation canal (Catalonia-Aragon). We treated all the water lost as evaporated and added an extra 1% to represent evaporative losses for the various water uses (Canals et al. 2010).
- **Fruit losses:** According to Food and Agriculture Technology Institute (IRTA) experimental data, the water losses during storing phases is quantified as 3%. The amount of fruit loss during the distribution stage is calculated as 15%. Fruit waste and losses in homes is quantified as 17% (WRAP 2008).
- **Electricity:** The electricity consumed by irrigation pumps was known, and the impact of generation and distribution of electricity demand was estimated using information from the ecoinvent database v3 according to the Spanish electricity low voltage mix.
- **Packaging materials:** For packaging materials, the water used for plastic and cardboard box use was considered (Life Cycle Inventories of Packaging and Graphical Paper. ecoinvent 2007).
- **Agrochemical substances:** The water consumed in insecticide and fungicide production and use was taken into account from the ecoinvent database v3.
- **Fertilizer production**: The impact and the water involved in fertilizer production were taken into account from the ecoinvent database v3.
- **Machinery:** Water for machinery production and diesel consumed for machinery operations were also taken from the ecoinvent database v.3.
- **Materials and substances:** Water related to materials and substances production involved to fruit production were also taken from the ecoinvent database v.3.
- **Transport of input materials and substances to the orchard:** It was considered the water related to vehicles uses and production: 7.5 t lorry, and the distance covered was 150 km. Small van <3.5t and the distance, 15 km.

5.3. Results and discussion

The results of the study will be presented according to the different approaches used: FAO Guidelines and ISO 14046.

5.3.1. FAO Water footprint results

Table 5.2 presents the results of the WF for apple and peach production, using the FAO guideline approach. According to the results, for apple production the water footprint is 575m^3/t, and for peach 681 m^3/t. The green component refers to rainwater stored in the soil. The blue component refers to surface and groundwater, and the grey water component is the volume of freshwater required to assimilate the pollutant load.

Table 5.2 Results of FAO WF quantification for apple and peach production

Method	**Apple**			**Peach**		
Approach	**FAO direct**	**FAO indirect**	**FAO Total**	**FAO direct**	**FAO indirect**	**FAO Total**
Units	m^3/t	m^3/t	m^3/t	m^3/t	m^3/t	m^3/t
Green	284	-	284	309	-	309
Blue	71	180	251	68	*261*	329
Grey	40	-	40	43	-	43
Total	***395***	***180***	***575***	***420***	***261***	***681***

Table 5.3 shows the contribution of direct water and indirect water consumption related to the total WF quantification. Of the total WF, for apple 395 m^3/t it is accounted for as direct water and 180 m^3/t as indirect water. In the case of peach, it is accounted 420 m^3/t for direct water and 261 m^3/t as indirect water. It can be observed that, for the entire fruit production cycle, direct water is accounted for as 62% to 69% and indirect water as 31% to 38%.

Table 5.3 Distribution of total water consumption for apple and peach depending on origin

Stage	**Apple**		**Peach**	
	m^3/t	**%**	m^3/t	%
Direct	395	69	420	62
Indirect	180	31	261	38
Total	***575***	**-**	***681***	**-**

Table 5.4 presents the distribution of the WF for fruit production depending on the stage where water is consumed. According to the results, agricultural production accounted for 92% of the total water footprint in both fruits, followed by the retail stage with around 7% and the consumption stage with 1%. Results are coherent with other publications about the WF of products; however, these previous studies were not performed applying ISO 14046 (Ridoutt et al. 2010; Herath et al. 2013).

Table 5.4 Distribution of total water consumption for apple and peach production depending on the stage.

Stage	**Apple**		**Peach**	
	m^3/t	**%**	m^3/t	%
Agricultural	531	92	629	92
Retail	38	7	45	7
Consumption	6	1	7	1
Total	***575***		***681***	

5.3.1.1. Importance of regional data in water consumption calculation

Table 5.5 presents the water consumption values obtained in this study for apple and peach production in the area under study (Catalonia) using only the FAO approach and compares the values obtained with other values published for the FAO for other regions. The default WF values for Spain presented in the FAO Report are based on WF values for 3 regions: Balearic Islands, Andalusia and Aragon.

According to the FAO average (2011), the WF for apple production for irrigated systems is 822 m^3/t. If we compare the FAO average values with the values obtained in this study (FAO Catalonia), this represents a difference of from 25-30%, depending on the fruit. This difference is explained because the FAO quantification is a global average of different countries of the world for a short period of time. On the other hand, our study only focuses on the cultivation period and is an accumulated average of 9 years of production with real climate and production data. The difference might arise from climatic and geographic factors (annual rainfall and temperature, etc.), as well as other factors such as soil type and different producing regions. As reported by (Dourte et al. 2014), very different blue water footprints can be expected between regions, even those with similar soils, management, and yields, due to seasonal rainfall differences, evaporative demands, and the corresponding impacts on irrigation requirements.

If we compare the values of our study with the different regions of Spain analysed for the FAO 2011 (Andalusia, Balearic Islands and Aragon), the difference varies from 1-23% depending on the fruit and region. According to (Iglesias, 2013), Andalusia and the Balearic Islands contribute less than 10% each to total Spanish peach production, whereas Catalonia produces more than

25% and Aragon 22%. Regions like Andalusia and the Balearic Islands are low rain areas that have many irrigation requirements and low production. This can mean that the WF results are higher than in our study, since Catalonia is an area where rainfall and the weather are appropriate to obtain a high yield.

Another factor to be considered is whether the WF is calculated for an irrigated system or a rainfed system, because results can differ considerably, especially in those areas where irrigation is needed. According to (Salmoral et al. 2011), in rainfed systems, the rainfall and temperature patterns contribute to the fruit production, whereas irrigated orchard production depends mainly on temperature, since water stress is usually avoided by the irrigation water supply. CROPWAT simulations reveal that effective rainfall is higher in rainfed orchards than in irrigated ones, since the irrigation water application decreases the green water evaporated. According to (Geerts and Raes 2009), the total water used per hectare is lower under drip than under gravity irrigation.

Caution should be taken when average values of different locations are used to calculate the WF, because using data from areas that have a rainfall or irrigation deficit or areas with low production can increase the total WF value in the results. According to (Pfister et al. 2009), for an appropriate assessment of water use, regionalization is crucial to capture the hydrological condition. Therefore, from the point of view of data quality, it is also essential to have local and multiyear values to avoid confusing or unreliable results (Vinyes et al. 2015; Jefferies et al. 2012).

Table 5.5 Comparison of different FAO WF values for peach and apple

Apple	**Units**	**Study Catalonia FAO**	**FAO Average**	**FAO Baleares Islands**	**FAO Andalusia**	**FAO Aragon**
Green	m^3/t	284	561	289	243	329
Blue	m^3/t	251	133	119	280	115
Grey	m^3/t	40	127	60	55	62
Total WFP	*m^3/t*	*575*	*822*	*468*	*578*	*506*
Difference	*%*	*-*	*30*	*19*	*1*	*12*

Peach	**Units**	**Study Catalonia FAO**	**FAO Average**	**FAO Baleares Islands**	**FAO Andalusia**	**FAO Aragon**
Green	m^3/t	309	583	353	307	397
Blue	m^3/t	329	188	131	311	130
Grey	m^3/t	43	139	75	71	77
Total WFP	*m^3/t*	*681*	*910*	*559*	*689*	*604*
Difference	*%*		*25*	*18*	*1*	*11*

5.3.2. ISO Water footprint results

Table 5.6 presents the results related to an LCA study undertaken according to ISO 14046:2015 in order to quantify the WF associated with fruit production in terms of water use impact. Results are presented in m^3 according to the WSI index (consumption-availability ratio calculated as the fraction between consumed and available water). These results allow us to identify the most important processes or life cycle stages in terms of water consumption, taking into account the relative scarcity where water is consumed. For apple production, the WF is 520 m^3/t, and for peach 647 m^3/t.

Table 5.6 Results of ISO WF results for apple and peach production

	Apple			**Peach**		
Approach	**ISO direct**	**ISO indirect**	**ISO Total**	**ISO direct**	**ISO indirect**	**ISO Total**
Units	m^3/t	m^3/t		m^3/t	m^3/t	
Total	***349***	***171***	***520***	***459***	***189***	***647***

Table 5.7 presents the distribution of the WF impact for fruit production depending on the stage. According to the results, agricultural production accounted for around 92% of the total water footprint impact for fruits, the retail stage around 6% and the consumption stage 2%.

Table 5.7 Distribution of ISO WF impact values for apple and peach production depending on the stage.

Stage	**Apple**		**Peach**	
	m^3/t	**%**	m^3/t	%
Agricultural	478	92	595	92
Retail	32	6	39	6
Consumption	10	2	13	2
Total	***520***		***647***	

5.3.3. Water footprint approaches comparison.

After calculating the WF, it is necessary to see how to use the methodologies available as a tool to determine water saving policies in fruit production. First of all, it should be clarified that FAO guidelines and ISO 14046 come from different backgrounds, apply different system boundaries and are used for different purposes: the FAO approach quantifies the amount of water use from a water resource management perspective, and ISO takes an LCA perspective and indicates the water use impact.

Other important differences are described below:

FAO calculation distinguishes between three components - green, blue and grey component - and LCA accounts for it differently. With LCA, water accounted for in the inventory is considered as blue water. For grey water, it is allocated with other impact categories, such as eutrophication water depletion or freshwater ecotoxicity. Green water consumption is considered in the LCA inventory but not considered in LCA impact characterization because it does not generally introduce significant changes in the local environment. While the FAO approach is a well-recognized approach for the calculation of evaporated water, especially in agricultural processes, with LCA few data are available on crop production.

LCA approach includes different impact characterization factors rather than only providing the volumes. However, the FAO focuses on water volume consumption, especially in the agricultural stage. To find data related to indirect water consumption with the FAO approach, it is necessary to use LCA databases. LCA characterization factors allow the volumes of water consumed in different regions to be weighted with different scarcity impacts, but this requires information on where consumption takes place and this information is often not available.

LCA approach is a consolidated methodology with a varied range of software and databases available, which allows the inclusion of more background information mainly focused on water related to industrial processes. The FAO WF approach is a recent methodology still under development.

5.3.4. Opportunities for improvement: Modelling fruit water efficiency alternatives.

Despite its methodological limitations (FAO or LCA), the water footprint has succeeded as an environmental and water use and consumption indicator. Considering that the agricultural stage accounts for around 94% of the total water footprint, a precise adjustment of irrigation crop water consumption is required in order to maximize the efficiency of irrigation and reduce the WF (Chapagain and Orr 2009). Traditionally, agricultural research has focused primarily on maximizing total production. In recent years, the focus has shifted to the limiting factors in production systems, notably the availability of either land or water (Geerts and Raes 2009).

The data for the water requirements of deciduous fruit and nut crops as a function of growth vary widely depending on climate, soil, and irrigation methods and management (Casadesús et al. 2011). Irrigation level and water status are known to affect yield and yield components: crop yield, fruit size and quality, growth habit, precocity, and long-term productivity (Girona et al. 2010). In areas where the water supply available limits agricultural production, deficit irrigation will gain importance over time as farmers strive to increase the productivity of their limited land and water resources (Chapagain et al. 2006).

Regulated deficit irrigation (RDI) has been widely investigated as a valuable and sustainable production strategy in dry regions (Girona and Ferreres 2010; Naor and Girona 2010). The objective of fruit irrigation management under suboptimal water allocation would be to minimize damage and maximize irrigation water productivity (Geerts and Raes 2009). RDI researchers use the terms ‘early-season’ or ‘late-season’ to describe the timing of their treatment application. Early season normally indicates the time period before flowering buds are formed for the next season’s fruit. For most varieties, early season will be before July in the Northern Hemisphere and before January in the Southern Hemisphere (García-Tejero et al. 2010).

A number of experiments have been conducted in the IRTA to quantify the relation between yield and irrigation water applied for peach and apple (Casadesús et al. 2012, 2011; Naor and Girona 2010; Girona and Ferreres 2010). The IRTA results from peach studies in Lleida concluded that the water applied can be reduced 10-20% below the maximum needs without having a negative impact on peach production yield. The results for apple determined a 15-20% reduction of water applied without affecting production. All the authors agreed that the response to water applied depends on the water storage capacity of the soil, and thus cannot be generalized. Girona and Ferreres (2010) report that when the water deficits were imposed on sensitive stages or throughout the season, a reduction in crop evapotranspiration was accompanied by a yield reduction. Therefore, early-season water stress reduces fruit size. According to (Naor and Girona 2010), water production functions for apple are difficult to generalize because they are affected by many factors, such as training system, crop load, pruning and thinning practices, and whether the target is total (as for juice production) or fresh marketable yields.

If RDI strategies were applied to the two orchards studied in this work, considering that the agricultural phase has an influence of 94%, reducing the irrigation water applied by 15% when possible, the values of the total WF would be reduced by 10% for apple (60 m^3/ton) and 9.5% (64 m^3/ton) for peach.

5.4. Conclusions

According to FAO guideline results, the water footprint was 575m3/t for apple production and 681 m3/t for peach. On the other hand, the results for the ISO 14046 approach in terms of Water scarcity index were 520 m^3/t for apple production and 647 m^3/t for peach. ISO WF results allow us to identify the most important processes or life cycle stages in terms of water consumption impact, taking into account the relative scarcity where water is consumed.

With both approaches, agricultural production accounted for 92.94% of the total water footprint in both fruits, followed by the retail stage, 4-6%, and the consumption stage, 1-2% m3/ton. It is observed that, for the entire fruit production cycle, direct water accounted for 62-29% and indirect water for 31-38%.

If we compare the two methodologies, we can note that FAO guidelines and ISO 14046 come from different backgrounds, apply different system boundaries and are used for different purposes: the FAO approach quantifies the amount of water use from a water resource management perspective, and ISO has an LCA perspective and accounts for the water use impact in terms of quality and scarcity.

Despite the differences between FAO and ISO approaches, after comparing them in depth using multiyear and local data, it seems that both methods are suitable for water consumption accounting, depending on the purpose of the study as well as the quality of the data available. The results of the study also reveal that it is feasible to combine the two methods for water accounting studies and related impact assessment. Even so, further research is needed in order to improve the data available and their allocation and characterization.

In terms of quality data, the results also demonstrate that, when the quantification indicator is linked to mass unit or yield, it is important to work with multiyear data. Also, working with local and regional data can help to avoid confusing or variable results. Deficit irrigation strategies play an important role in farm-level water management strategies in order to optimize water use efficiency and manage scarcity in agriculture and water footprint values. If RDI strategies were applied to the two orchards studied, reducing the irrigation water applied by 15% when possible, the values of the total WF could be reduced by 10%. It should therefore be noted that, in areas where the water supply available limits agricultural production, deficit irrigation will gain importance to help productivity, using limited water resources.

PART IV

CARBON FOOTPRINT OF FRUIT PRODUCTS

Chapter 6

Photography by Elisabet Vinyes

Carbon footprint and economic assessment of different apple cultivation systems: Central axis and Fruiting wall

Chapter 6. Carbon footprint of different apple cultivation systems: Central axis and Fruiting wall

Based on a manuscript by:
Vinyes, E., C.M. Gasol, L. Asin, S. Alegre, and P. Muñoz. 2016. Calculation of Carbon footprint of different apple cultivation systems: Central axis and Fruiting wall. Submitted in June 2016, to Journal of Industrial Ecology.

ABSTRACT

The study will compare two different training apple systems: Central axis and Fruiting wall, in order to detect the emissions difference in terms of Carbon footprint (CF), between them and provide useful environmental information to fruit producers.

According to results Central axis system has a CF of 0.207 $KgCO_{2eq}$ and Fruiting wall system 0.195 $KgCO_{2\text{-}eq}$, So Central axis system presents a higher CF values what means a difference of 6%. Central axis system has more number of trees per hectare and less infrastructure and machinery involved, but lower yield. On the other hand, Wall system has lower number of trees per hectare and requires more infrastructure and machinery, but the yield is higher so final CF values are reduced because the impact is distributed over the years.

In both systems Fertilization stage was identified as the main contributor (44%). The economic results reveal that Fruiting wall system is more profitable than Central axis system. This improved profitability is based on higher production and lower cost of pruning and hand thinning during the period of full production. Both factors are able to overcome higher costs of planting and management in the early years.

So the impact of the use of machinery and the infrastructure involved in orchard production is an important factor to be considered when training systems are compared, because depending on the yield the CF per kg of fruit produced can be higher.

6.1. Introduction

The world population increasing is generating a demand of agricultural products, as well as an intensive consumption of natural resources, water and energy, etc., generating and important environmental impact, and contributing intensively to the existential threat of climate change. The IPCC 2007 report estimates that the direct impact of agriculture is about 10–12% of global the global anthropogenic greenhouse gases emissions. Fruit production is considered an agricultural sector with a low contribution to environmental impacts compared to the herbaceous crops sector and other food (Cerutti et al. 2011c; Frey, S., Barrett, J. 2007; Martínez-Blanco et al. 2011).

At present, can find numerous environmental tools to evaluate the environmental impacts related to a process or a product. The LCA methodology proved to be a useful tool to evaluate the environmental damage of this agricultural activity (Martínez-Blanco et al. 2011; Milà i Canals 2003). LCA is a compilation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle (ISO14044 20), the environmental impact is expressed in different impact categories. So LCA is suitable when Carbon Footprint a product or a process want to be quantified. CF is defined as: the sum of greenhouse gas emissions and removals in a product system expressed as CO_2 equivalents, and based on a *life cycle assessment* using the single impact category of climate change (ISO 14067:2013).

Environmental information of food products is increasingly available becoming and accessible to the society, it has generated that both producers and consumers choose for a more sustainable production and consumption. To develop a sustainable environmental management, it is important that food producers analyses the main environmental indicators of their production processes, in order to detect environmental critical points related to their products. When assessing agricultural products using life cycle assessment (LCA), the farmers play a key role as they have first-hand information to understanding the activities involved in the assessed systems (Torres et al. 2016).

Catalonia is the Region of the Spain with the highest apple production with a production this means 54% of the total Spanish apple production and 46% of the total cultivated area (MAGRAMA 2014). The aim of this study is to calculate the Carbon Footprint (CF) of two different apple cultivation systems: Central axis and Fruiting wall, in order to detect the emissions difference related to different cultivation systems, and provide useful environmental information to fruit producers that help them to find the best practices in order to reduce CO_2 emissions of fruit production process. The study also includes an economic evaluation to compare the viability of the implementation of the different systems cultivation.

The data used in this study have been directly collected from a real orchard of Catalan Institute for Research and Technology in Food and Agriculture (IRTA) . Considering that the main impact in fruit production take place in agricultural stage (80%) (Milà i Canals 2003; Cerutti et al. 2011c), the study is focused only in cultivation stages, excluding the storage and commercialization phases. Multiyear approach described in a previous work by (Vinyes et al. 2015) has been applied to do the assessment and 9 years of cultivation has been considered.

6.2. Materials and methods

The CF is defined as: calculation of the amount of greenhouse gases (GHG) emitted into the atmosphere over the life cycle of a product, service or organization, expressed in kilograms of carbon dioxide equivalent: kg CO_{2eq} (PAS 2050:2008). The ISO14067 (Carbon Footprint of Products Requirements and Guidelines) publication has harmonized the method of calculation of CF unifying the different existing impact assessment models, in order to obtaining reliable and comparable results. ISO 14067:2013 defines CF as: "the sum of greenhouse gas emissions and removals in a product system expressed as CO_2 equivalents, and based on a life cycle assessment using the single impact category of climate change".

To calculate the CF of the two cultivation apple systems, it will be applied LCA approach according to ISO 14044:2010 and ISO 14067:2013, in order to find the difference between the two systems compared, and how infrastructure involved and multiyear approach affects the results.

6.2.1. LCA

LCA is defined by ISO standard (ISO14044:2010) as the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle. LCA analysis considers four main steps: aim and scope, inventory analysis, impact assessment, and interpretation of results. The end results are dependent on the systems boundaries and the functional unit (FU), which is the unit to which the results of the LCA are related, and subsequently used for the communication of the LCA results.

Considering that the aim of this study, only CHG impact category have been considered. Calculation method used is Recipe Midpoint H. Calculations were performed with the software SimaPro 8.1, together with the ecoinvent Centre database 3.1. According to (Milà i Canals et al. 2006; Cerutti et al. 2011b) a mass-based functional unit is adequate when analysing only the agricultural stages of the life cycle of fruit for descriptive purposes. So in this study the functional unit has been defined as "cultivation of 1kg of apple". In Appendix I it can be founded supplementary material related to chapter 6.

6.2.2. Economic assessment

To define, from the point of view of profitability, which is the best training system (Central axis or fruiting wall), it has conducted a simple economic study with real production data, during every year of the trial. The economic study is not intended to establish the cost of production of kg of apple, but the comparison between different assay systems.

For economic analysis it has taken into account the following considerations: It has been considered the current price costs. The analysis includes the installation of drip irrigation and fertirrigation. Costs of manual work, costs of machinery labour, costs of machinery acquisition, and rental costs of machinery specialized. It also includes cost of insurance for crop losses by weather. Annual costs related with other work management, administration and taxes.

It has been considered costs 9 years of production. It not takes into account possible differences in the life of the plantation. But it has considered the Planting costs, which includes soil preparation, fertilization, materials, labour and interest generated during the first year.

For the economic analysis the following indicators are used:

- **IRR (Internal Rate of Return):** Annual average profitability of the plantation.

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0$$

Where:

Ct = net cash inflow during the period t
Co= total initial investment costs
r = discount rate, and
t = number of time periods

- **NPV (Net Present Value):** By the discount rate all annual balances generated by the investment are updated.

IRR (Internal Rate of Return): Annual average profitability of the plantation.

Internal rate of return is a metric used in capital budgeting measuring the profitability of potential investments. IRR makes the net present value (NPV) of all cash flows from a particular project equal to zero.

NPV (Net Present Value): Discount rate all annual balances generated by the investment are updated. It represents the present value of the retained earnings of the entire plantation life.

The analysis includes the following costs:

- Installation of drip irrigation system
- Costs of manual work
- costs of machinery labour
- Costs of machinery acquisition
- Rental costs of machinery specialized
- Cost of insurance for crop losses by weather
- Annual costs related with other work management
- Administration costs and taxes.
- Planting cost: soil preparation, fertilization, materials, installation of irrigation

Since economic results depend on the price charged for the product, and it can have strong variations in 9 years, it has worked with three price assumptions keeping constant the ratio of price variation between different calibres (data average price and price variations between calibres have been obtained from historical data of 10 years).

6.3. System description

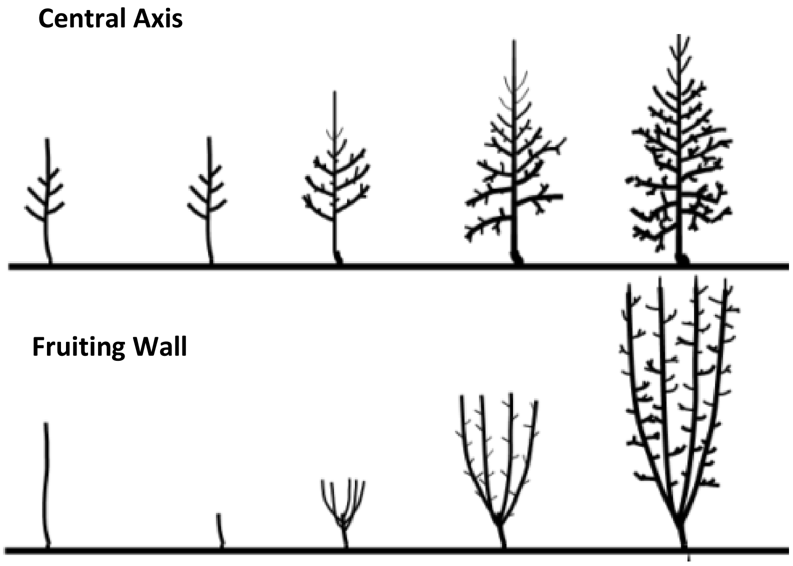
Two apple orchards will be compared according their cultivations system: Central axis or Fruiting wall. Both orchards are apple type *Brookfield® Gala,* and apply integrated agricultural practices according specifications of European Integrated Farming Framework (European Commission 2012). Nine years of cultivation have been considered from year 2004 to 2012). The two orchard plots are located in Lleida, Catalonia (Spain) and have a surface of 1,500 m^2. Table 6.1 and Figure 6.1 describes the 2 systems compared Central axis and Fruiting wall, and their structure system.

The study focuses only in the cultivation period, distribution and consumption stages have been excluded. Initial orchard establishment tasks are included: soil preparation and plantation. The stages considered for the cultivation period are: fertilization, irrigation, pest management, weed mowing, pruning and harvest. Post-harvest operations (storage, processing, packaging and use) are not included. Figure 6.2 shows the boundaries of the system studied. Different management tasks are involved during the fruit cultivation, soil preparation and plantation tasks were performed by tractor mechanical work, and these stages are only done once at the beginning of the plantation planting. Agrochemicals were applied with a tractor and a sprayer. Fertilizers were applied through the irrigation system (fertirrigation) with electric pumps Pruning was done manually and mechanized depending on the season, and the wood was crushed with a tractor implement. Weed mowing was done with a tractor implement. Harvest was done manually, but required an elevation platform and a tractor to transport the fruit to the storehouse. To performance LCA approach, a part of cultivation stages, the following inputs have been taken in account to make the inventory: production of fertilizers and their application to the field, pest management substances manufacture and their application (fungicides and insecticides), machinery manufacture and implements used with their and their transport to the orchard, water use, and energy use.

Table 6.1 Description Central axis and Fruiting wall cultivation system according IRTA data

System	Central Axis	Fruiting Wall
Frame (m)	4 x 1,25	3,5 x 1,5
Density (tree/ha)	2.000	1.905
Average fruit Production (t/ha)	43.4	48.8
Average pruning (hours)	66.7	38.2
System description	The trees were planted without any cut, tied to a support structure so that they could grow freely. From the second year the shaft remained uncut and when there were too many branches it is prunned to maintain the structure.	After planting, the plants were cut 50 cm to cause the output of vigorous new branches, these branches are tied to the support system regularly distributed, forming a structure of four-axis palm. From the second year, at the time of the year that an outbreak about 12 leaves, mechanical pruning is done to maintain the structure.
Structure		

Figure 6.1 Strucuture of different training systems; Central Axis and Fruiting Wall



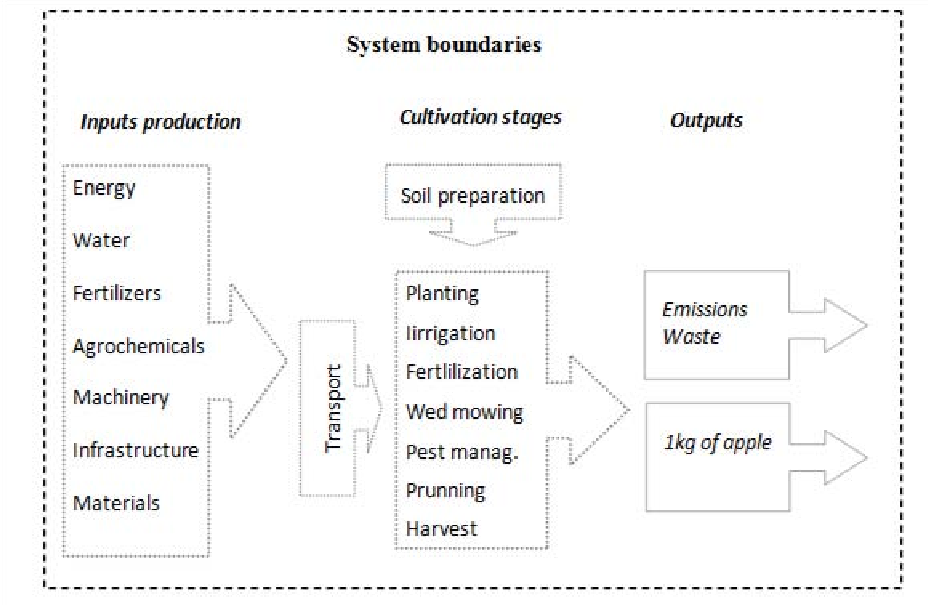


Figure 6.2 Boundaries of the apple systems system studied

6.4. Inventory data

The Data used to elaborate the inventory is experimental data that have been directly collected from orchards of Catalan Research Institute of Food and Agriculture Technology (IRTA). Soil preparation and fruit tree planting were done during the first year. Full production was achieved from the fifth year for both systems. Central axis system achieve maximum production in year eight (48.6 t/h) and Fruiting wall system in year seven (51.7 t/ha). For the study it have been considered an average production of 43.4 t/ha for Central axis system and 48.8 t/ha for Wall.

Table 6.2 shows the inventory data for each system. Background system involved in apple cultivation also has been considered, it includes: water, materials, resources, energy, infrastructure and other raw materials involved in all the other sub-systems.

Table 6.2 Inventory of input data considered for apple cultivation using Central axis and Fruiting wall systems.

Data	Central Axis	Fruiting Wall	Units
Yield	43	49	ton/year
Water	6,434,167	6,013,240	m^3/t
Diesel	481	509	l/kg
Electricity	1,950	1,945	kw/kg
Fertilizers:			
N	103	111	kg/t
P_2O_5	86	93	Kg/t
K_2O	28	30	Kg/t
Machinery	47	58	Kg/t
Agrochemicals	52	51	Kg/t
Infrastructure			
Iron	55	69	Kg/t
Wood	498	623	Kg/t
Plastic	554	692	Kg/t

6.4.1. Data assumptions

In order to optimize the application of the methodologies, some assumptions have been made in accordance to previous work (Vinyes et al. 2015). The number of machinery operations and the working hours for running the machines and their implements have been obtained from IRTA real data. Emissions of machinery production and diesel consumed for machinery operations have also been taken from ecoinvent database v.3.1 (ecoinvent Centre). Irrigation water came from a Catalan public irrigation canal (Catalonia-Aragon), the orchard was irrigated with electric pumps, the amount of water and electricity consumed was known from IRTA experimental data, the impact of generation and distribution of electricity demand was estimated using information from ecoinvent database v3.1, according to the Spanish electricity mix of low voltage (Ecoinvent Centre). The active ingredients of the pesticides and fungicides used have been taken into account from ecoinvent database v3.1 (ecoinvent Centre). Regarding to fertilizers emissions, it has been considered the emissions of fertilizer production and the emissions of fertilizers used have been taken into account. Nitrogen (N_2O), phosphorus (P_2O_5) and potassium (K_2O) emissions were modelled according to the literature (Brentrup et al. 2001; Audsley 1997). For transport of materials and substances to the orchard it was assumed that the vehicle used to transport the materials and substances from the production plant to the local point of sale was a 7.5 t lorry, and the distance covered was 150km. The vehicle considered to deliver the materials from the regional cooperative to the plantation was a small van<3.5t and the distance, 15km. For Carbon sequestration, no specific land and biomass carbon sequestrations were taken into account in this work, as the soil carbon content remained constant during the years of the study, and there was no change in the use of the land. Biogenic carbon has not been considered as either kidnapped or as issued, because is for temporary short chain. It was assumed that the land occupied is arable and that it had been used for agriculture for a long time. Therefore, according previous work (Vinyes et al. 2013) no impacts caused by land transformation were taken into account as the plot has been an orchard for more than 25 years (ISO14067).

6.5. Results and discussion

The results of the study are presented in different sets: agricultural stages emissions (6.5.1), emissions evolution (6.5.2), and economic results (6.5.3).

6.5.1. Agricultural stages emissions

Results are expressed according to the functional unit chosen: “production of 1kilogram apple”. Table 6.3 shows the emissions values in kg CO_{2eq} for each agricultural stage considered and for each system, and he also percentage contribution the emissions stages related to the total emissions.

Table 6.3 Emissions related to agricultural stages per FU depending on the system

System	Central axis		Fruiting wall	
	Emissions	***%***	***Emissions***	***%***
Stage	kg CO_{2eq}		kg CO_{2eq}	
Soil preparation	0,0017	0,81%	0,0015	0,79%
Planting	0,0031	1,48%	0,0030	1,52%
Fertirrigation	0,0930	44,99%	0,0866	44,36%
Pest management	0,0450	21,75%	0,0419	21,44%
Pruning	0,0092	4,44%	0,0114	5,85%
Moving	0,0027	1,32%	0,0025	1,30%
harvest	0,0521	25,21%	0,0483	24,73%
TOTAL	0,2067		0,1953	

According to results showed in table 3, the emissions related to Central axis are 0.207 $KgCO_{2eq}$ and for Fruiting wall system 0.195 $KgCO_{2eq}$ So Central axis system presents higher total emissions values what means a difference of 6%, although in planting and pruning stages Central axis system presents lower emissions values. In both systems, Fertirrigation stage was identified as the main contributor (44%), it is explained because the production processes of mineral fertilizers emit a large amount of $CO_{2,}$ as well as the nitrous oxides. Harvest stage also has a significant contribution to total emissions (24-25%); it is explained because this stage requires several machinery hours to take the fruit produced from the orchard to the storing house, so the large use of machinery and diesel contributes considerably to $CO_{2,}$ emissions account. Pest management has a contribution similar for both systems (21%) again due to the large use of machinery. Pruning also uses machinery but fewer hours so its contribution is (4-5%). Moving and planting has a similar contribution (1.30-1.50%). It can be observed that Soil preparation has the lowest contributor (0.79-0.81%) for both systems. The results obtained are coherent with fruit publications with similar agricultural stages. Emissions contribution obtained are consistent with the values range obtained for other fruit studies (Milà i Canals et al. 2006; Alaphilippe et al. 2013; Cerutti et al. 2010; Coltro et al. 2009; Iriarte et al. 2014; Mithraratne et al. 2008; Ingwersen 2012; Torres et al. 2016).

6.5.2. Emissions evolution

Figure 6.3 shows the evolution of the total emissions over 9 years related to kg of apple cultivation depending on the system studied: Central axis or Fruiting wall. Figure 6.3 also shows the contribution of each input considered in the inventory per year: machinery, material, transport, water, diesel, electricity, fertilizers and agrochemicals substances. The dashed line of the graph means the evolution of kg CO_{2eq} per kg of apple and per year (according to right axis).

It can be observed for both systems that in the first year there is no significant production, but from the second year, when fruit production begins to increase, then the quantification of kg CO_{2eq} per kg of apple value decreases and trends towards stabilization. For wall system the maxim yield is achieved in year 5 so the amount of CO_2 emissions gets the lowest value over 0.120 CO_{2eq} For Central axis system maximum yield is achieved in year 9 with lowest CO_2 emissions quantification near 0.120 CO_{2eq} even so Fruiting wall system has high values of CO_2 in some years, when multiyear approach is applied it can be observed that the global value of emission is lower than Central axis system. So results obtained reinforce the implementation of the multiyear approach described by (Vinyes et al. 2015) in order to detect differences in yield variability, and not just focus on one or two years of production. Of the all inputs considered in the study, for both systems (Central axis and fruiting wall) fertilizers show the highest contribution over the nine years, followed by electricity, diesel, agrochemicals, water, machinery and transport. It can be observed that emissions quantification of the most indicators remains constant over the nine years, but fertilizers emissions are directly dependent on the fruit production and reach the maximum application when the fruit production is high, on the contrary the CF is lower these years when de kg produced are higher.

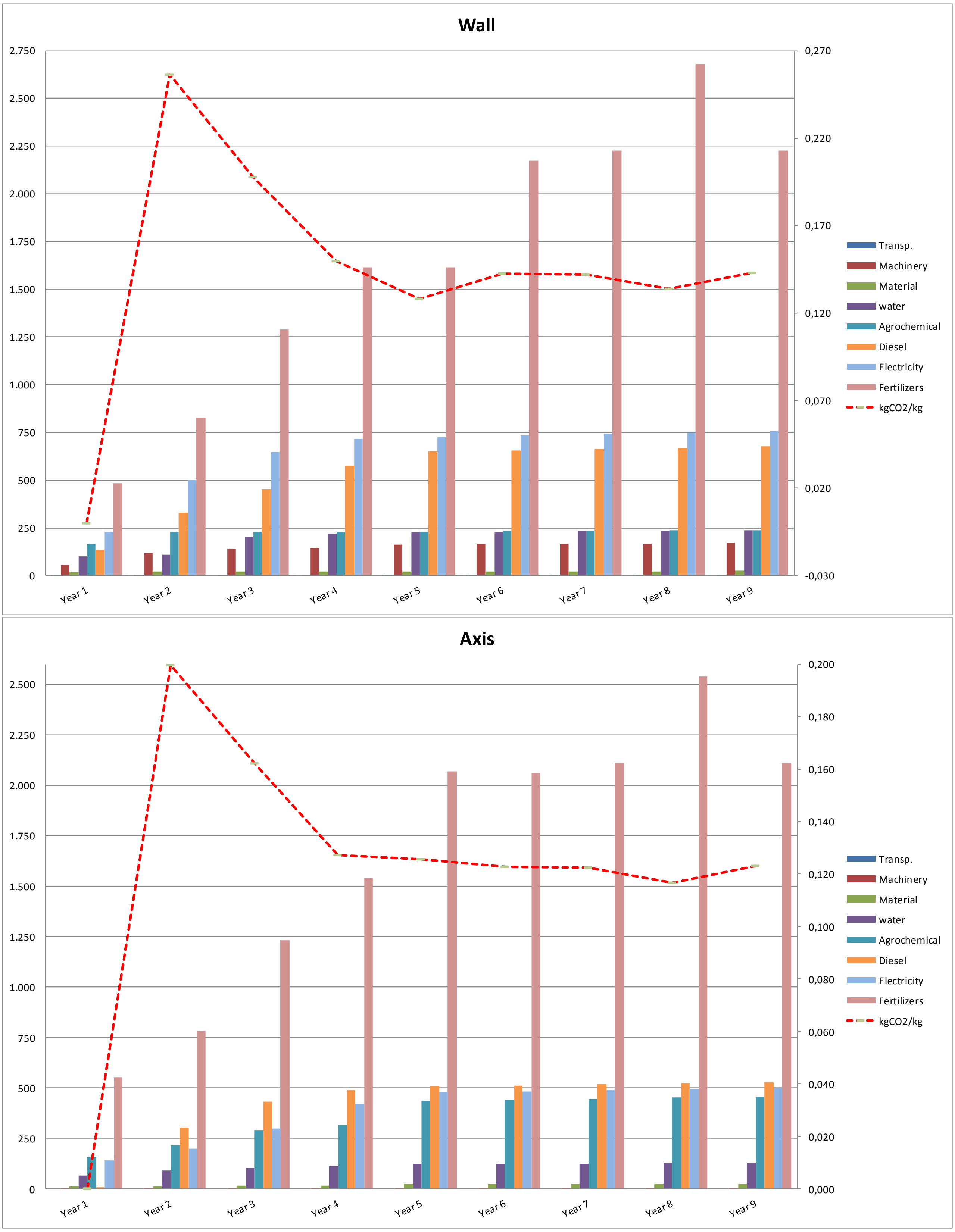


Figure 6.3 Evolution of the total emissions over 9 years related to kg of apple cultivation depending on the system studied: Central axis or Fruiting wall

6.5.3. Economic results

Table 6.4 shows the economic results depending on the different costs considered planting costs annual costs in full production, global costs.

Table 6.4 Economic results of comparing Central axis and Fruiting wall system

System	Planting costs	Annual costs full production.	Global costs
Central Axis	19,308 €/ha	8,200 €/ha	5,000€/ha
Fruiting Wall	20,016 €/ha	8,000 €/ha	6,000€/ha

When planting costs are compared it can be observed that, there is a difference of 708€/ha, Fruiting wall system presents higher costs. The determining factor for this difference is the number of trees/ha: 2,000 for Central axis and 1,905 for Fruiting wall system. A part from this, there are other factors affecting the final planting cost even less influence, as is the number of poles per hectare and that the necessary iron wire is superior in the Fruiting wall.

Regarding the annual costs in full production (excluding depreciation and amortization, interest and capital), there is a difference of 200€/ha between the two systems. Central axis presents higher value with an amount of 8,200€/ha. The most important cost is the collection stage that reaches about 2,500€/ha, representing 31% of the annual cost. The second major cost is for maintenance (phytosanitary treatments, plant growth regulators, herbicides, wed mov and fertilizers) representing 29% of all annual costs.

In terms of global costs, there is a difference of 1.000€/ha between systems. This difference makes that the profitability expressed in terms of IRR and NPV are more favourable for Fruiting wall system, with a NPV of approximately 12,000 € / ha, and an IRR of 2.7%.

So the results obtained in the economic study indicate that in a long-term, Fruiting wall system is economically more profitable, although the cost of investment of the Fruitng wall assay is superior. This final advantage of Fruiting wall is mainly based on superior production in the period of full production about 12 and 18%. In addition to this, wall system has a lower maintenance cost because they is a systems that require a lower cost in the manual pruning and thinning. In the case of pruning, although it must be added the cost of mechanical pruning, this cost is offset by a reduced need for winter pruning in Fruiting wall scompared to the Central axis. As well Fruiting walls system require less hours of manual thinning.

Because the goal of the study was to compare the two systems from an environmental point of view, the economic study done was only payback guidance on infrastructure issues, the development of a more complete and deep economic study will be left pending for further reseacrh.

6.6. Conclusions

So comparing apple cultivation systems Central axis and Fruiting wall has allowed finding the differences between them in terms of emissions, productivity and profitability. The study also has been able to detect which agricultural stages have the highest impact in terms of CF in apple agricultural practices.

According to results Central axis system has a CF of 0.207 KgCO_{2eq} and Fruiting wall 0.195 Kg$CO_{2\text{-}q}$, So Central axis system presents a higher CF values what means a difference of 6%. Fruiting wall system has more infrastructure, materials, and tasks involved, as well some manual tasks can be mechanized what means more machinery hours and more diesel consumption, but this system has more production over the years so the final value of CF is reduced because the impact is distributed among more kg produced. Results obtained reinforce the implementation of the multiyear approach described by (Vinyes et al. 2015) in order to detect environmental differences in yield variability.

In both systems Fertirrigation was identified as the stage with high contribution (44%), it is explained because the production processes of mineral fertilizers emit a large amount of $CO_{2,}$ as well as the nitrous oxides. Consequently Fertilizers inputs and management is an important factor to be considered for GHG emissions reduction planning.

The economic study results show that Fruiting wall system is more profitable than the Central axis system; this better profitability is based on higher fruit production and lower pruning during tasks the period of full production. In both systems the most important cost is the collection stage that means 31% of the annual cost.

In addition to the economic advantages in a long term of Fruiting wall system, remarks that it allows a plan a training system in order to mechanize some tasks, as mechanical thinning, that’s important for those fruit varieties which show reduced efficacy with chemical rinses and consequently require manual thinning to adjust the load of trees. So the positive results obtained for Wall system can be used as an argument for fruit producers and authorities, to promote or enhance a system that has very good results concerning to agronomic, economic and environmental aspects.

PART V

GENERAL CONCLUSIONS AND FURTHER RESEARCH

Chapter 7

Photography by Elisabet Vinyes

Conclusions and contribution

Chapter 7. Conclusions and contribution

This chapter outlines the main conclusions and contributions of this dissertation, and the objectives achievement.

7.1. Objective achievement and conclusions

The aim of this dissertation is to assess an environmental analysis from a sustainable perspective of fruit production in Catalonia, focused on apple and peach production. In Chapter 1 three main objectives were proposed to achieve the target of the dissertation.

Objective I:

Analyse the methodology available for Life Cycle Assessment, carbon footprint and water footprint applied to agricultural production. Detect the variability of results depending on the data and methodology chosen.

To perform the environmental analysis of fruit production in Catalonia LCA methodology has been used, and the results have been expressed in terms of carbon footprint (CF) and water footprint (WF), and LCA environmental indicators.

Chapter 4 results show that agricultural phase presents the highest contribution in the total environmental impact, followed by retail stage, consumption and disposal. Results related to the CF confirm that the retail stage makes a contribution in total emissions of 39%, the agricultural stage 36%, the consumption stage 24% and disposal 1%.

Chapter 5 results indicate that agricultural production accounted for 92.94% of the total water footprint, followed by the retail stage, 4-6%, and the consumption stage, 1-2%. It is observed that, for the entire fruit production cycle, direct water accounted for 62-29% and indirect water for 31-38%.

During the research, it has been perceived that many environmental studies published only consider the agricultural stage and have no information related to the retail, consumption and disposal stages, they mainly focus on one productive year, while the life span of fruit plantations can be longer than 15 years (depending on the fruit or the country).

- **LCA approach**

According to the results obtained in the different chapters (3,4,5,6) LCA is a useful tool for estimating the impact associated with a product or process, but there are still some questions to be resolved regarding to the quality of environmental information and environmental impact databases available, because sometimes, is need to work with generic data, specially in the case of pesticides or fertilizers, so it may vary the results depending on the generic data selected.

In **Chapter 3** and **Chapter 4,** LCA methodology has been used in accordance to ISO 14040:2006 to achieve the environmental analysis of multiyear peach production. According to the results multiyear approach is strongly recommended when the functional unit is related to yield. It is also important to have data related to other variables related to yield as geographic location and climatic conditions, for many periods of time as possible, to reflect these variables in the results. It was observed that using different range of productive years scenarios, can generate a variation in the environmental impact results between 7% and 69%, depending on the impact indicator.

- **Carbon footprint approach**

In **Chapter 6**, CF of two apple cultivation systems has been calculated, applying LCA approach according to ISO 14044:2010 and ISO 14067:2013, in order to find the difference between the two production systems and how the infrastructure involved and multiyear approach affects the results. After the literature research, it has been perceived that the publication ISO14067 (Carbon Footprint of Products Requirements and Guidelines) has been useful to harmonize the method of calculation of CF unifying the different existing impact assessment models (PAS 2050, PAS 2050-1) in order to obtaining reliable and comparable results. A previous methodology as PAS 2050 excludes the emissions arising from the infrastructure and production of capital goods, such as machinery or buildings, whereas the LCA includes them.

The impact of the use of machinery and the infrastructure involved in orchard production is an important factor to be considered when production systems are compared, because depending on the yield and the years of cultivation considered, the CF per kg of fruit produced can be higher due to the impact of infrastructure and machinery involved. If the use of machinery and the infrastructure involved is not considered in the analysis it can generates a variation in the results of 28% of the total emissions.

- **Water footprint approach**

In **Chapter 5,** WF of fruit production has been quantified using Standard ISO14046:2015 and complemented with FAO water footprint guidelines, in order to quantify water consumption associated with these products (direct and indirect water) and the potential impacts of water use and associated pollution, as well as to detect the regional differences related to climate variations and fruit trees evapotranspiration requirements.

Although the differences between FAO and ISO14046:2015 water footprint approaches, after comparing and combining them using multiyear and local data, it look like that both methods are suitable for water consumption accounting, but depending on the purpose of the study and the quality of the data available. It is important to emphasis that, FAO guidelines and ISO 14046 come from different backgrounds, apply different system boundaries, and also are used for different purposes. FAO approach quantifies the amount of water use from a water resource management perspective, and ISO takes an LCA perspective and indicates the water use impact.

FAO calculation distinguishes between three components: green, blue and grey component and LCA accounts for it differently. In LCA method all water accounted in the inventory is considered as blue water. Grey water is allocated with other impact categories, such as eutrophication water depletion or freshwater ecotoxicity. Green water consumption is considered in the LCA inventory, but not in LCA impact characterization phase because it is consideredthat does not introduce significant changes in the local environment, rain water is not accounted either in LCA.

LCA approach includes different impact characterization factors rather than only providing the volumes. But, the FAO focuses only on water volume consumption, especially in the agricultural stage and the environmental impact only is evaluated in the grey component. To find data related to indirect water consumption in the FAO approach, it is necessary to use LCA databases. So FAO approach is a well-recognized approach for the calculation of evaporated water, especially in agricultural processes, however in LCA approach few data are available on crop production.

LCA characterization factors allow the volumes of water consumed in different regions to be weighted with different scarcity impacts, but this requires information on where consumption takes place and this information sometimes is not available. Even so Apply two methods together will allow having all the information available for the ISO in case that some day will be updated to include the impact of green water.

Objective II:

Provide suggestions for improving the methodology for calculating carbon footprint and water footprint, so they can be applied to agricultural production. Analyse data processing and how it needs to be considered in agricultural inventories, in order to provide new information on fruit production.

- **Quality data and regional data**

In terms of quality data, the results obtained in **Chapter 3, Chapter 4 Chapter 5, Chapter 6** demonstrate that when the quantification of environmental indicators are linked to mass unit or yield, it is important to work with data for many years as possible (multiyear approach), in order to reflect the variability the yield and climatic an geographic conditions in the results.

Even so multiyear approach is strongly recommended, sometimes a lack of data makes it difficult to make an agricultural inventory and include all stages related. So, it is essential to encourage the farmers and food producers to keep as many data as possible, for many periods as possible, and with a reliable quality. In this work it has been possible to work with real and local data from experimental orchards of IRTA, all of this has allowed to get a more realistic values than use generic database data.

In agricultural production, is important to consider that yield variability not only depends on the orchard age, it also strongly depends on other variables such as fruit variety, geographic location, planting frame, climatic conditions, irrigation system, fertilizers supply and pest control optimization.

- **Multiyear approach**

According to the results obtained in CF and WF assessments, for orchards with an average life time of twenty years or longer, a multiyear approach is strongly recommended when the functional unit is related to kg produced. Because when the functional unit is related to mass and only a single year is studied, the years that the yield is low the impact values per functional unit increase Depending on the scenario considered single year or multiyear, the environmental contribution of each impact category can vary between 7%-69%. Also, it is important working with local and regional data in order to avoid confusing or distorted results of using generic data.

Geographic location of fruit orchards is also an important aspect to be considered in agricultural data collection phase, because in temperate areas orchards reach maturity as early as two years after the plantation, and reach full production from the fifth year, which can significantly affect yield average and environmental results, depending on the amount of years taken into account.

Objective III:

Detect critical environmental points of the fruit production cycle, in order to provide environmental information to fruit sector actors involved, and to propose improvements in their process.

- **Fruit production cycle**

When the entire cycle of fruit production is analysed in **Chapter 4** results shows that agricultural phase presents the highest contribution in the total environmental impact, followed by retail stage, consumption and disposal. Results related to the carbon footprint show that the retail stage makes a contribution in total emissions of 39%, the agricultural stage 36%, the consumption stage 24% and disposal 1%. Regarding to emissions related to fruit losses during the entire fruit production cycle, are quantified above 10% of the total emissions for fruits, apple and peach.

According to IRTA experimental data, the fruit losses during agricultural stage is quantified as 3%, fruit loss during retail stage is 15%, and Fruit waste/losses at houses are quantified as 17%. So it is necessary for authorities to promote more sustainable consumption at a domestic level. Further research is needed to educate all the actors involved in the retail stages and consumers at home that they need to change certain behaviours to avoid losses and food waste, and especially in the current context of global warming and resource depletion.

In terms of WF, results obtained in **Chapter 5** shows that agricultural production accounted for 92.94% of the total water footprint, followed by the retail stage, 4-6%, and the consumption stage, 1-2%. It is observed that, for the entire fruit production cycle, direct water accounted for 62-29% and indirect water for 31-38%. IRTA experimental results demonstrate that when deficit irrigation strategies were applied to the two orchards studied, the irrigation water applied was reduced 15%, and the values of the total WF 10%.

Considering the actual context of resources depletion, deficit irrigation strategies play an important role in water management policies in order to optimize water use efficiency and manage scarcity in agriculture, to help productivity, using limited water resources, especially for these areas where the water supply available limits agricultural production.

From the point of view of data quality, caution should be taken when average values of different locations are used to calculate the WF, because using data from areas that have a rainfall or irrigation deficit or areas with low production can increase the total WF value in the results.

- **Agricultural stages**

Regarding to the environmental impact related to agricultural stages, the results of **Chapter 3 and 4** indicate that, of the all agricultural stages considered, fertirrigation is the stage that presents the highest contribution percentage in 10 of the 14 impact categories studied, with a maximum contribution of 99.93% in WDP category and a minimum contribution of 45.66% in FDP category. Pest management presents the highest contribution in the remaining impact categories, with a maximum of 64.50% in Etox category and a minimum of 47.22% in ODP.

The high environmental impact of fertirrigation stage is explained because manufacturing of fertilizers and pesticides have a significant impact. Weed mowing, pruning and harvest impacts are mainly due to the use of machinery, and their involvement in the cultivation process is more sporadic than fertigation. Concerning to orchard establishment tasks: soil preparation and planting, if they are not included in the inventory, a 5% of total emissions can be overlooked, anyways a lack of data makes it difficult to inventory and include these stages.

The emissions quantification done in **Chapter 6,** identify Fertirrigation stage as the main to CO_2 emissions contributor (44%), it is explained because the production processes of mineral fertilizers emit a large amount of CO_2, as well as the nitrous oxides. Harvest stage also has a significant contribution to total emissions (24-25%) because in this stage a lot of machinery hours are involved, Pest management (21%), Pruning (4-5%), Moving and planting (1.30-1.50%). Soil preparation has the lowest contributor (0.79-0.81%) for both systems.

Consequently, it is essential to encourage the farmers to consider the orchard design and its geographic location to promote a better orchard environmental performance, and attempt to choose another kind of fertilizer with low environmental impact, encourage them to try to regulate the application dose, and improve the monitoring of nutrients contents in soil and crop. Sensitivity analysis reveals that a modification of 10% in fertilizers field management scenarios can mean a variation from 15% to 17%.

- **System production**

The economic study performed in **Chapter 6,** in order to compare two apple production systems, shows that Fruiting Wall system is more profitable and sustainable than the Central Central Axis system; this better profitability is based on higher fruit production and lower pruning during tasks the period of full production. In both systems the most important cost is the collection stage that means 31% of the annual cost, so the positive results obtained for Fruiting wall system can be used as an argument for fruit producers to promote or enhance a system that has very good results concerning to agronomic, economic and environmental aspects, when sustainable production is planned.

7.2. Contribution of this dissertation

This section outlines the methodological and environmental contributions of this dissertation, in order to support the development of further studies on the topic of sustainable agriculture and food production.

- **Methodological contributions**

Regarding to methodological aspects, this thesis proposes an additional methodological perspective as is the introduction of multiyear approach in order to avoid variability in the results when they are linked to annual yield. As well as detect the variability of the results depending on the methodology chosed as well as the regional and geographic data used.

Resulting from Chapters 3 and 4, the thesis contributes to improve LCA methodology in order to be better applied to agricultural systems. These chapters also make an analysis of the agricultural data available and also how this data need to be considered in agricultural inventories and allocations. These chapters also contribute to complete the existing fruit LCA literature and provide new environmental information for peach and apple analysis, as well as introducing a multiyear perspective analysis to identify the variability of results related to annual yield, fruit varieties, climatic conditions and geographic location. Agricultural data used was direct collected from IRTA experimental orchards what has allowed working with a reliable and high-quality experimental dataset and avoid unnecessary assumptions.

Chapters 5 and 6 analyse the available methodologies for quantifying the carbon footprint and water footprint, and contribute to analyse their application to agricultural and fruit products, in order to detect the strengths and weaknesses of these methodologies and purposes some improvements, as is the use of local and regional data, local water scarcity index, and how to make the data inventory.

- **Environmental contributions**

Regarding to environmental aspects, considering the actual context of sustainable development, a part from contributing to improve the methodological tools available, this thesis also contributes to detect the critical environmental points related to the fruit production cycle, because all the actors involved (farmers, food companies, consumers, stakeholders) to have the essential information, in order to introduce improvement strategies in their processes to offer more sustainable products, as well as contribute to a sustainable development. This work also aims to contribute to obtain to environmental quality information so that producers can use this information to communicate to consumers the environmental aspects of the products which they consume.

7.3. Further research

This section identifies future research lines around the topics analysed throughout this dissertation.

- **LCA inventory data (Chapter 3 and 4):**

Even though it has been confirmed that LCA is a useful tool for estimating the environmental impact associated with a product or process, there are still some issues to be resolved regarding to the quality of environmental impact databases and data available, especially when the inventory is done, because sometimes, due the need to work with generic data and assumptions (as in the case of active substances of pesticides or fertilizers) depending on the substance selected it can generate an important variation in the impact results.

- **CF approach (Chapter 4 and 6)**

Emissions related to fruit losses during the entire fruit production cycle, is quantified above 10% of the total emissions. Fruit waste at houses is quantified as 17% of the total losses, so it is necessary for authorities to promote more sustainable consumption at a domestic level.

Further research is needed to awareness all the actors involved in the retail stages and consumers, it is essential to change certain behaviours to avoid food losses and food waste, and especially in the current context of global warming and resource depletion.

- **WF approach (Chapter 5)**

FAO guidelines and ISO 14046 come from different backgrounds, apply different system boundaries and are used for different purposes. The FAO approach quantifies the amount of water use from a water resource management perspective, and ISO takes an LCA perspective and indicates the water use impact.

The results of the research reveal that it is feasible to combine the two methods (FAO guidelines and ISO 14046) for water accounting studies and related impact assessment, but further research is needed in order to improve the data available and their allocation and characterization, because FAO approach quantifies the amount of water use from a water resource management perspective, and ISO takes an LCA perspective for the water use impact.

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APPENDIX I.

Supplementary material related to chapter 6

1. Introduction

The aim of this Appendix is to complement **Chapter 6**, and calculate the carbon footprint (CF) of peach production in Catalonia expressed as kilograms CO_{2eq}, using two of the main available standards: LCA approach (according to ISO 14044 and fruits and nuts Product Category Rules (PCR), and the PAS 2050 (British Standards Institute 2008) approach (in accordance with PAS 2050-1(BSI. British Standards Institute 2012).

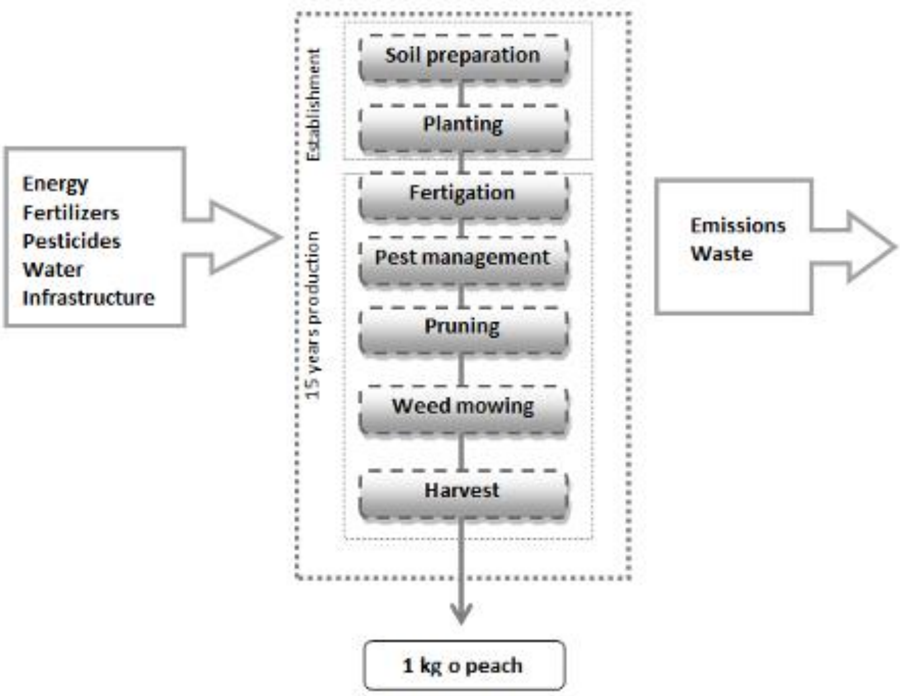
2. Materials and methods.

To calculate the CF of peach production in Catalonia, two standard methods have been applied and compared: LCA approach (ISO 1404420) and PAS2050 and in accordance with PAS 2050-1.Table 1 shows the boundary of the system studied. Figure 1shows the sytem boundaries.

2.1 Main differences between CFP standards.

In both standards, LCA and PAS 2050-1, some assumptions have to be made in order to adapt the available data to the software. Assumptions details are described in section 2.6. Table 1 shows the differences between PAS 2050-1 and LCA methodologies for the system studied

As regards figure of system boundaries, they differ depending on the method approach applied, because PAS 2050-1 excludes the emissions arising from the infrastructure and production of capital goods, such as machinery or buildings, whereas the LCA includes them. Nevertheless the consumables considered in PAS 2050-1 differ from capital goods, in that they have an expected life of one year or less, or a need to replenish on a one year or less basis. Another difference is that PAS 2050-1 includes change of land use emissions whereas LCA does not. In this study change of land use has not been considered, because according to PAS 2050-1 specifications, if the same crop has been cultivated in the same plot for over 25 years it is not necessary consider change of land use. The consumption of energy, the use of raw materials, the waste treatment and emissions generated during the production stage of mineral fertilizers and agro-chemical substances, are considered for both methodologies, but the infrastructure of production plants and its disposal are not included in PAS2050-1.



Appendix 1 Figure 1. System boundaries.

Appendix 2 Table 1. Summary Table of input data considered for the cultivation of 1kg of peach

Production scenarios		**Growth**	**Low prod**	**High prod**	**Multiyear**
INPUTS					
From the technosphere					
Energy inputs	Units				
Diesel	g	8.49	5.35	4.48	6.04
Electricity	kwh	0.06	0.03	0.03	0.04
Transport	tkm	1.2	1.31	1.31	1.28
Materials inputs					
Fertilizers:					
K_2O	g	4.91	2.84	2.38	3.10
N_2O	g	4.96	2.87	2.40	3.14
P_2O_5	g	0.67	0.39	0.33	0.43
Agrochemicals:		0.00	0.00	0.00	0.00
fungicides (generic)	g	2.25	1.04	0.87	1.18
insecticides (generic)	g	0.56	0.26	0.22	0.30
Machinery:					
Use	g	0.76	0.48	0.40	0.54
Accessories	g	0.05	0.04	0.04	0.05
Water	l	347.43	197.65	165.72	216.93
OUTPUTS					
To the technosphere					
Peach	kg	18.745	40.540	48.350	36.280
Emissions to the atmosphere					
Diesel:					
CO_2	g	25.95	16.35	13.71	18.47
SO_2	mg	4.98	5.29	4.44	5.98
VOC	mg	18.46	25.15	21.08	28.41
NO_X	mg	16.28	23.23	19.23	26.79
NH_3	mg	0.07	0.10	0.09	0.12
CH_4	mg	0.42	0.68	0.57	0.76
N_2O	mg	0.41	0.63	0.53	0.71
Fertilizers:					
N_2O	mg	$6.04E^{-03}$	$3.49E^{-03}$	$1.03E^{-04}$	$5.20E\text{-}^{03}$
NH_3	mg	$1.27E\text{-}^{02}$	$7.34E\text{-}^{03}$	$7.34E^{-03}$	$1.09E^{-02}$

3. Results and discussion.

The results of the study are presented in different sets: agricultural stages emissions (3.1), and fertilizers field management sensitivity analysis (3.2).

3.1 Agricultural stages emissions

Results are expressed according to the functional unit chosen: "production of 1kilogram of peach" for fifteen years of production. Table 2 shows the different emissions values in kg CO_{2eq} per kg of peach related to each agricultural stage considered for LCA and PAS 2050-1, and the difference between them. Table 2 also displays the percentage contribution of each agricultural stage related to the total emissions.

The LCA method shows a higher number of total CO_{2eq} emissions in all stages, as this approach considers the impact of the machinery used and the infrastructure involved, whereas PAS 2050-1 excludes all of them. LCA includes the impacts of the materials and substances production, transport infrastructure (roads) and the infrastructure of field cultivation (irrigation and buildings), whereas PAS 2050-1 does not consider any type of infrastructure or machinery. The difference for the total emissions per kg of peach cultivated depending of the approach is 28.96%. This difference means a quantification of 0.0622 kg CO_{2eq} kg^{-1}. The difference obtained is similar to other works that also compare emissions calculation methodologies described in the work by Martinez-Blanco (2015).

Weed mowing is the stage with the highest difference (73.72 %), followed nearly by pruning (68.20%), pest management (66.55%), and harvest (57.81%). The difference in these stages is due to many machinery operations being performed. The remaining stages where not much machinery is involved have a contribution between 12 - 26%.

Appendix 3 Table 2. Emissions differences between agricultural stages depending on the approach

	Total Emissions			Stage Contribution	
	LCA	**PAS 2050-1**	***Difference***	**LCA**	**PAS 2050-1**
Stage	***kg CO_{2eq} kg $^{-1}$***	***kg CO_{2eq} kg $^{-1}$***	***%***	***%***	***%***
Soil preparation	0.0012	0.0011	12.97%	0.58%	0.71%
Planting	0.0011	0.0008	26.55%	0.50%	0.51%
Fertirrigation	0.1458	0.1278	12.31%	67.79%	83.69%
Pest management	0.0492	0.0165	66.55%	22.90%	10.78%
Pruning	0.0024	0.0008	68.20%	1.12%	0.50%
Weed mowing	0.0040	0.0011	73.72%	1.86%	0.69%
Harvest	0.0113	0.0048	57.81%	5.26%	3.12%
TOTAL	0.2150	0.1528	28.96%		

As regards the percentage contribution of each agricultural stage to the total emissions, fertirrigation was identified as the main contributor in both methodologies (67.79% - 83.69%). The production processes of mineral fertilizers emit a large amount of CO_2, as well as the nitrous oxides contribution. Soil preparation is the lowest contributor (0.58% - 0.71 %). Even so some machinery is involved in initial stages. Emissions related to soil preparation and planting are distributed over fifteen years of production. As there is a lack of peach cultivation studies to compare the results obtained, these were compared with fruit publications with similar agricultural stages. Emissions contribution obtained are consistent with the values range obtained for apple studies by (Milà i Canals et al. 2006; Cerutti et al. 2014).

3.2 Fertilizers field management sensitivity analysis

According to the results obtained in Table 3, fertilizers are the input with the highest contribution to total CO_{2eq} emissions. Sensitivity analysis has been performed in order to assume different fertilizers management scenarios. Sensitivity analysis is a systematic procedure to estimate the effects of the choice made as regards methods and data on the outcome of a study. It helps to judge whether the collected data and scientific assumptions of a model are valid.

Sensitivity analysis has been developed according to fertilization guide of Spanish Ministry of Environment (2012). Three scenarios have been defined for fertilizers: Real input, Low input and High input. Low input means a reduction of 10 % the real amount of fertilizers, and High inputs means an increase of 10%. Standard deviation (SD) has been calculated for each fertilizers scenario during the fifteen years. Table 4 shows the statistics results.

Appendix 4 Table 3. Sensitivity analysis for fertilizers management emissions during 15 years.

LCA	**Fertilizers range emissions:** $kg\ CO_{2-eq}\ kg\ peach^{-1}$				**Fertilizers emissions variation**
	Mean	**MAX**	**MIN**	**SD**	**%**
Real input	0.1733	0.2697	0.1358	± 0.0327	±15.20%
Low input	0.1565	0.2427	0.1223	± 0.0291	±15.04%
High input	0.1912	0.2967	0.1494	± 0.0356	±16.41%

PAS 2050-1	**Fertilizers range emissions** $kg\ CO_{2-eq}\ kg\ peach^{-1}$				**Fertilizers emissions variation**
	Mean	**MAX**	**MIN**	**SD**	**%**
Real input	0.1310	0.0510	0.0259	± 0.1528	±16.96%
Low input	0.1179	0.0459	0.0232	± 0.1433	±16.20%
High input	0.1441	0.0561	0.0284	± 0.1609	±17.66%

For Real input the variation of the total peach emissions is ±15.20% for LCA and ±16.96% for PAS 2050-1. For Low input the variation is ±15.04% to ±16.20 %, and for High input variation is ±16.41% to ±17.66%.

Sensitivity analysis reveals that a modification of 10% in fertilizers field management scenarios can mean a variation from 15% to 17% of the total peach emissions depending on the assessment: LCA or PAS 2050-1. Therefore fertilizers inputs and management is an important factor to be considered when GHG emissions are quantified, and when a CO_{2-eq}. reduction is planned for companies.