An initiative of the Food Sector for the protection of the environment

LIFE+ FOODPRINT

LIFE13 ENV/GR/000958

Action B.1: Development of a Carbon Footprint tool for the effective quantification of CO_2 equivalent emissions sources of pastry and flour products/Development of a state of the art database

Activity B.1(a): Literature review and evaluation on the state-of-the-science computer-based carbon footprint reduction software tools for the food supply industry existing worldwide

Deliverable B.1(a)	**Literature review and evaluation on the state-of-the art science computer-based carbon footprint reduction software tools for the food supply industry existing worldwide**

Athens, March 2015

Version 1

Acknowledgements

This report was produced under co-finance of the European financial instrument for the Environment (LIFE+) as the Deliverable B.1(a) (*Literature review and evaluation on the state-of-the-science computer-based carbon footprint reduction software tools for the food supply industry existing worldwide*) of the Action B.1 (*Development of a Carbon Footprint tool for the effective quantification of CO_2 equivalent emission sources of pastry and flour products/Development of a state of the art database*) of Project "FOODPRINT" (LIFE13 ENV/GR/000958) entitled "An initiative of the Food Sector for the protection of the environment".

FOODPRINT team would like to acknowledge the European financial instrument for the Environment (LIFE+) for the financial support[1].

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ABBREVIATIONS AND ACRONYMS

AGDCC	Australian Government, Department of Climate Change
AFI	Australian Farm Institute
AHDB	Agriculture & Horticulture DEVELOPMENT BOARD
CFF	Climate Friendly Food
CFI	Cool Farm Institute
CFT	Cool Farm Tool
CHP	Combined Heat and Power
CO_2	Carbon dioxide
CSV	Comma Separated Values
defra	Department for Environment, Food & Rural Affairs
DfT	Department for Transport
DNDC	DeNitrification DeComposition
DOE	Department of Energy
EC	European Commission
EIOLCA	Economic Input-Output Life Cycle Assessment
EOS	Institute for the Study of Earth, Oceans and Space
EPA	Environmental Protection Agency
EU	European Union
FQD	Fuel Quality Directive
GHG	Greenhouse Gas
GP	General Practitioner
GWP	Global Warming Potential
HGCA	Home Grown Cereals Authority
ICCA	International Congress and Convention Association
ICF	International and Colorado State University
ILCD	International Reference Life Cycle Data System
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Center
kg	kilogram
LCA	Life Cycle Assessment
LCD	Low Carbon Diet
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCVP	Low Carbon Vehicle Partnership
LUC	Land Use Control
LULUCF	Land Use, Land Use Change and Forestry
MAC curve or MACC	Marginal Abatement Cost curve
MAGB	Maltsters Association of Great Britain
MCA	Multi Criteria Analysis
MCDA	Multi-criteria decision analysis
N	Nitrogen

NGGI	National Greenhouse Gas Inventory
NPD	New Product Development
PLCA	Process Life Cycle Approach
RAEL	Renewable and Appropriate Energy Laboratory
RED	Renewable Energy Directive
RFA	Renewable Fuel Agency
RSB	Roundtable on Sustainable Biomaterials
RTFO	Renewable Transport Fuel Obligation
RUSLE	Revised Universal Soil Loss Equation
SAFA	Sustainability Assessment of Food and Agriculture Systems
SME	Small and Medium-sized Enterprises
UK	United Kingdom
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Porgramme
UNH	University of New Hampshire
US	United States
USA	United States of America
VCA	Vehicle Certification Agency
WMO	Word Meteorological Organization
WRI	World Resources Institute

e.g.	exempli gratia
et al.	et alia
etc	et cetera
i.e.	Id est

EXECUTIVE SUMMARY

In recent years the rise in living standards and the subsequent change of consumption patterns have led to a significant environmental problems, some of which are related to the production of gaseous pollutants.

Certain gaseous pollutants are either directly or indirectly linked to the change of the main equilibrium in climate. The industrial sector leads the production of gaseous emissions, even enterprises that do not belong in the heavy industry. It has been confirmed that food and drink industry –subject of the LIFE FOODPRINT project- along with agriculture are responsible for the 29% of the global greenhouse gas (GHG) emissions worldwide (Ramos et al., 2014).

Therefore, it is of high importance to conduct studies of environmental sustainability of products regarding the identification of carbon dioxide CO_2 hotspots.

Nevertheless, due to the complexity of food chains, the large number of associated members and the variety of the available machinery important issues are raised regarding the software used for the conduction of these environmental studies. The results of these studies, as well as the solutions proposed contribute towards the mitigation of the environmental problem intensity and the opening of opportunities for the food industries. In particular, these software tools are useful for small and medium-sized enterprises (SMEs) of the food industry that do not use economic resources in order to assess the sustainability of their products. In this context, there are several software tools available for the conduction of sustainability assessments of products. The types of software tools available are carbon footprint calculators, decision support tools or sometimes a combinations of these types.

In order to create a software tool that shall reduce the GHG emissions from pastry and flour industry, a thorough literature review is necessary for the construction of an up-to-date software tool. In this deliverable -B1a: "Literature review and evaluation on the state-of-the-science computer-based carbon footprint reduction software tools for the food supply industry existing worldwide"- key parameters of carefully selected software tools are outlined. More specifically, two main sections are included within following the introductory chapter (Chapter 1) regarding the different types of models available.

In the first set of software tools described, carbon calculators. Some of these calculators refer to the food sector while the rest to agriculture and the food and supply chain. The chapter following (Chapter 4) includes decision support tools that are mainly used in the agriculture and food sector. Both chapters are accompanied by evaluations of the selected tools, which highlight the advantages and their weakest software features.

In the last chapter, general conclusions are comprised, as well as the best characteristics of the carbon calculators and decision support tools available, in order to prepare all the necessary input data for constructing the FOODPRINT software tool.

1 INTRODUCTION

1.1 Aim and Objectives

This deliverable is the result of the Implementation Action, Activity B1a of the LIFE+ FOODPRINT project that refers to the "Literature review and evaluation of the state-of-the-science computer-based carbon footprint reduction software tools for the food supply industry worldwide". The aim of this Activity is the recording of cutting-edge software tools for the carbon footprint calculation, as well as associated decision support tools.

The common objective of both the description of carbon footprint calculators and decision support tools is the careful selection of tools that refer to the production line of the flour and pastry industry. In this context, the aforementioned types of tools selected will refer to each of the stages followed for the production of the flour and pastry industry, i.e. from the stage of the production of crops till the manufacture of products reaching the shelves.

Each tool is fully described and then evaluated in order to provide all the necessary input data for constructing the FOODPRINT software tool.

1.2 Type of models

Rapid increase in energy consumption and extensive resource use have been associated with hazardous gases. The anthropogenic global warming deriving from these harmful gas emissions has turned out to be one of the most severe environmental problems during the latest decades. Various metrics have been used over the years, in order to clarify the contributions of the different types of emissions to the climate change. Nevertheless, there is no single solution for measuring the intensity and comparing the impacts of the different emissions due to various limitations and uncertainties (WMO and UNEP, 2013).

During the last decades, the quantification of the exclusive total amount of carbon dioxide emissions that is directly or indirectly caused by an activity or is accumulated over the life stages of a product (i.e. carbon footprint) has received high attention (Wiedmann and Minx, 2008). The carbon footprint, also called carbon profile, is calculated by using environmental indicators, such as the Global Warming Potential (GWP). The aforementioned metric is based on the cumulative radiative forcing over a particular time horizon (WMO and UNEP, 2013) and relates the contribution of a greenhouse gas to the climate change regarding a fixed time period (i.e. GWP_{100} refers to 100 years) (IPCC, 2007). In this context, IPCC has released a very detailed list, which is updated periodically, containing all the types of GHGs and their contribution to the GWP measured in kg-CO_2 equivalents (defra et al., 2011).

In this deliverable, the carbon calculators included compute the emissions of the most common GHGs from certain activities associated with the production line of flour and pastry industry, in order to highlight their contribution to the GWP (based on the equivalences presented in the following Table 1). In addition, the decision support tools presented in this deliverable, depending on the aforementioned calculations, suggest measures for the reduction of the GHG emissions.

Table 1 GWP of the most common GHGs

GHG	Chemical formula	GWP100 (kg-CO_2 equivalent)
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298
CFC-11	CCl_2F	4,750
CFC-12	CCl_2F_2	10,900
CFC-13	$CClF_3$	14,400
Carbon tetrachloride	CCl_4	1,400
Methyl bromide	CH_3Br	5
Methyl chloroform	CH_3CCl_3	146
HFC-23	CHF_3	14,800
HFC-32	CH_2F_2	675
Sulfur hexafluoride	SF_6	22,800
Nitrogen trifluoride	NF_3	17,200
PFC-14	CF_4	7,390
PFC-116	C_2F_6	12,200
Dimethylether	CH_3OCH_3	1
Methylene chloride	CH_2Cl_2	8.7
Methyl chloride	CH_3Cl	13

Source: defra et al., 2008

The climate change or the GWP of a good or a service is equal to the following equation (Guinée et al., 2002):

$$Climate\_Change = \sum_i GWP_i \cdot m_i \quad \text{(Eq.1)}$$

Where the GWP_i is the GWP index of the substance (i in kg-CO_2 equivalents/kg of substance i), m_i is the mass of the substance (i in kg) and *Climate Change (or GWP)* is the environmental indicator in kg-CO_2 equivalents.

More specifically, the GWP index has been estimated for each substance based on the increased infrared absorption due to the emission of 1kg of the substance, divided by the infrared absorption occurred from 1kg of the substance and the equal emission of carbon dioxide both integrated over time (Guinée et al., 2002). The cumulative impact of GHGs is calculated for specific time horizons (e.g. 100 or 500 years), while “direct effects” are assessed for smaller time intervals (e.g. 20 or 50 years). It has to be noticed that unreliability of the GWP index becomes stronger at longer time periods. Nonetheless, the GWP_{100} is the most commonly used metric for the measurement of the contribution of a good or service to the climate change.

The calculation of the carbon equivalents of GHG emissions (i.e. carbon footprint) from the production of goods or service provision is frequently implemented under the scope of a life cycle analysis or also called Life Cycle Assessment (LCA). LCA is a methodology used to assess the environmental burden of a product, process or activity throughout its life cycle (i.e. cradle-to-grave approach). It applies an interdisciplinary analysis combining numerous considerations for developing sustainable practices. Sectors under consideration in this methodology are the extraction of raw materials, New Product Development (NPD), disposal and/or recycling, as well as the transportation of the abovementioned inputs/outputs. In specific, the parameters considered for the calculation of the GHG emissions of the abovementioned stages are the energy and material inputs, as well as the wastes produced and the under-examination product.

It has to be noted that an LCA is a lot more than measuring the contribution of a product or service to climate change, as the latter is only one of the many environmental impact categories. Other categories, such as the eutrophication and acidification potential and many more impacts are listed in Table 2 (Guinée et al., 2002). As a result, it becomes obvious that the carbon footprint is associated to the LCA of a product or service, focusing on the emissions that intensify climate change. LCA is an extremely useful tool, since:

- ✓ it highlights environmental “hot spots” in a product’s life cycle,
- ✓ compares different environmental impacts for various competitive products,
- ✓ identifies opportunities for environmental improvements and
- ✓ improves/optimizes processes with respect to the various environmental burdens.

Table 2 The most important impact categories accessed from an LCA study

Impact category	Units
Eutrophication potential	kg PO_4 equivalents
Acidification potential	kg SO_2 equivalents
Ecotoxicity and human toxicity potential	kg 1,4-DB (1,4-dichlorobenzene) equivalents
Photochemical ozone creation potential–smog	kg C_2H_2 equivalents
Ozone depletion potential	kg CFC-11 equivalents
Depletion of Abiotic resources	kg Sb equivalents

Source: Guinée et al., 2002

2 CARBON FOOTPRINT TOOLS

2.1 Introduction

A "footprint" is considered as a quantitative measurement for the appropriation of natural resources by humans (Hoekstra, 2008; Cucek et al., 2012). As a result, there are different footprints, such as environmental, social and economic footprints. Among the various environmental footprints, the carbon footprint is one of the most important environmental protection indicator (Wiedman and Minx, 2008; Lam et al., 2010; Galli et al., 2012, Cucek et al., 2012). In specific, the carbon footprint represents the amount of CO_2 and other gaseous emissions intensifying the climate change (in CO_2 equivalents) produced from the life cycle of a process or product (BSI, 2008; Cucek et al., 2012). The quantification of the carbon footprint comprises indicators, such as the GWP.

Carbon footprint is also characterized as one of the key LCA results (ICCA and Responsible Care, 2013), since it is a result of Life Cycle Thinking applied to global warming. As mentioned before, LCA is not limited only to global warming and covers several impact categories (Stechemesser and Guenther, 2012). Therefore, the selection of impact categories depends on the purpose of conducting and LCA, as well as on the type of application of the LCA (Danish Ministry of the Environment, 2005). A well-aimed LCA is useful for avoiding problem-shifting, such as from one stage of the life cycle to another (Finnveden et al., 2009).

In this context, software carbon footprint calculators have been developed for different activities, such as the production line of flour and pastry industry. Carbon calculators designed for such cases are constructed as tools available in quantitative GHGs impact assessments resulting from the industry production or the product consumption (Amani and Schiefer, 2011). As there are many tools developed for footprint evaluation, a number of such tools focuses on simple and rapid calculation of the carbon footprint or other indicators (Cucek et al., 2012).

There are several web-based carbon footprint calculators, which although they lack in consistency and information sufficiency about their methods and estimates, they promote public awareness through individual behavior change (Cucek et al., 2012; Padget et al., 2008). In general, the methodology used in constructing carbon calculators involves the acceptance of user's characteristics by returning an amount of carbon dioxide/carbon dioxide equivalent emitted that representing the user's carbon footprint (Padgett et al., 2008).

It becomes eminent that the more complex the life cycle of a product is, the more comprehensive databases are required to conduct a successful LCA or part of an LCA, such as the carbon footprint. Nowadays, the use of LCA or software carbon footprint tools has become indispensable, since a growing number of companies conduct sustainability assessments of their products. Such software tools include detailed and accurate libraries with the most common industrial processes, such as the production and use of liquid fuels and/or the production and use of electricity. Furthermore, there are accounting tools that have focused on specific aspects of industrial sectors (e.g. the building/constructing sector, waste management sector, transportation sector, the food and agriculture sector etc). Moreover, during the past few years, several carbon calculators have been released by various organisations for measuring the carbon footprint of different sectors of products or services in a more practical way. Certain carbon calculator tools that focus on the food and agriculture sector are listed in the following table (Table 3) and discussed in the following chapters (2.2-2.17).

Table 3 List of carbon calculator tools for the food sector

Sector	Tool
Food sector	FoodCarbonScope™
	Footprint Reporter™
	LCD
	Cool Climate Carbon Footprint Calculator
	FoodCarbon Footprint Calculator
Arable crops	CLA CALM
	CCalc
	Organic Farmer Carbon Calculator
	CFT v1.1
	Muntons barley calculator v4
	Biograce calculator v4b
	RFA-RTFO Carbon Calculator v1.0
	BEATv2
	RSB Tool
	HGCA Biofuel GHG Calculator
Food & supply chain	SENSE tool

2.2 FoodCarbonScope™

2.2.1 Overview

Table 4 FoodCarbonScope™

General characteristics of FoodCarbonScope™ tool	
Tool name	FoodCarbonScope™
Developer name	CleanMetrics™ Analytics for the Sustainable Economy
General boundaries	Farm-to-fork (cradle-to-gate)
Language of interface	English
Access/Installation Requirements	Available online. Paid license for the use of the website. http://www.cleanmetrics.com/html/foodcarbonscope.htm

FoodCarbonScope™ is a web-based LCA software tool for the modeling and analysis of life cycle GHG emissions, energy use and water use in food and beverage production line. The tool focuses mainly on the sustainable production and consumption in the food and beverage industry (CleanMetrics Corp, 2015).
The calculator uses the Process Life Cycle Approach (PLCA) for the life-cycle assessment and carbon footprint analysis for the products, and complies with applicable international standards (ISO 14040:2006, PAS 2050 and GHG Protocol) (CleanMetrics™, 2015).

2.2.2 Methods / Technical characteristics

This cross-sector tool (referring to restaurants, retail and food production) covers over 100 food products (e.g. meat, dairy, seafood, cereals, grains, legumes, vegetables, fruits, frozen foods, baked goods, some processed foods etc), bearing a high level of specificity thus low aggregation. In this context, many processes are included in this calculator covering the product life cycle (Amani and Schiefer, 2011).

As a result, an extensive Life Cycle Inventory (LCI) database was necessary to be constructed, in order to cover all the stages in the life cycle of food and beverage products and develop precise product life models (CleanMetrics™, 2011). It has to be noted that the highest level of confidence in data accuracy relies with plant-based foods (CleanMetrics™, 2015; Kim et al., 2008).

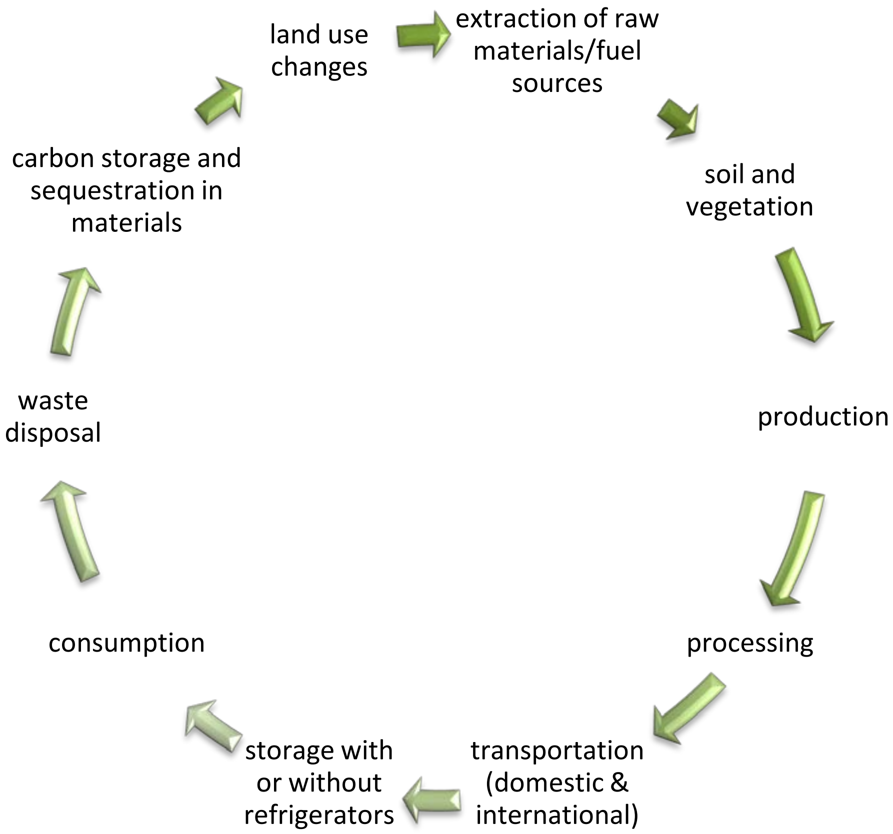

Figure 1: Processes included in FoodCarbonScope™ tool

Since FoodCarbonScope™ provides a range of integrated tools, users can compute the GHG emissions produced by the life cycle of a product, as well as compare more than two product life cycles or collections of products (CleanMetrics™, 2015). The tool also provides hierarchical model-building for complex life cycles. In addition, the analysis provided highlights the waste and inefficiencies in the production line, thus meeting specific reporting requirements and communicating of the results to supply-chain partners (CleanMetrics™, 2015). In this context, material-handling algorithms are used in order to track complex material and waste streams in product life cycles (Amani and Schiefer, 2011). The methodology behind the "Deep Carbon Footprinitng™" is based on time-dependent emissions and sequestration characteristics.

2.2.3 *Case studies*

FoodCarbonScope™ applies in different case scenarios under the scope of:

- Product eco-labeling
- Business-to-business and business-to-consumer sustainability assessments
- Environmental benchmarking of competitive food and beverage products
- Environmental hotspots
- Improvements in the production line

One of the best known applications of the FoodCarbonScope™ tool refers to the contribution for the development of the Low Carbon Calculator. More specifically, FoodCarbonScope™ results regarding the quantification of the food miles underlie the inventory included by Bon Appetit Management Company Foundation in the tool.

2.2.4 *Basic advantages / disadvantages*

Advantages

- FoodCarbonScope™ comes with an interactive, user friendly platform for analyzing complex product supply chains.
- The tool provides comprehensive analyses that cover efficiently the various product life cycles (cradle-to-grave approach) and accounts for all GHG emissions and resource use (CleanMetrics™, 2011; Wakeland et al., 2007).
- The LCI database of the tool is commercially available, including data not only for North American food production and processing but also for Europe and other parts of the world (CleanMetrics™, 2011).
- The LCA results provided are standards-compliant.
- FoodCarbonScope™ is a flexible tool that can be used for both the analysis of the product life cycle, as well as for the corporate value chain (scope 3) analysis (CleanMetrics Corp, 2015).
- The audit trails available in the tool are highly automated, providing reporting/documentation, technical reviews and certifications of the results more easily (Amani and Schiefer, 2011).

Disadvantages

- The use of CleanMetrics require subscription costs for each user (Kim et al., 2008), thereby limiting its possible applications.

2.3 *Footprint Reporter™*

2.3.1 *Overview*

Table 5 Footprint Reporter™

General characteristics of Footprint Reporter™ tool	
Tool name	Footprint Reporter™
Developer name	Best Foot Forward part of the Anthesis Consulting Group PLC
General boundaries	Farm-to-fork (cradle-to-gate)
Language of interface	English
Access/Installation Requirements	The basic version comes either with 30day free trial or with £1,500. The version for the enterprises costs a minimum of £5,000. A custom version is also available. https://footprintreporter.com/

Footprint Reporter^{TM} is a carbon footprint calculator referring to the measurement of GHG emissions from food production and consumption on an institutional level (Kim et al., 2008). Since the adoption of standards for methodologies and applications is important for the credibility of footprint measurements (Amani and Schiefer, 2011), Best Foot Forward works with the bodies involved in facilitating standards including the indicators of the Department for Environment, Food & Rural Affairs (defra), the Carbon Trust and the Global Footprint Network for ensuring that Footprint Reporter^{TM} remains compliant with existing and emerging standards. In this context, Footprint Reporter^{TM} is compliant with the guidelines provided by ISO 14064-1, as well as with the GHG Protocol (Kim et al. 2008).

2.3.2 *Methods / Technical characteristics*

Footprint Reporter^{TM} as a cross-sector tool (food, energy production, transport, materials and other products) covers all the stages of the supply chain up to retailing. It has to be noted that the range of food products covered is characterized of low specificity and high aggregation (e.g. there food groups available are dairy, meat and poultry, fish, cereals, beverages etc). It is worth mentioning that there is no distinction between organic and conventional production methods.

The tool assesses the ecological footprint and computes the CO_2 footprint using cradle-to-gate food LCA models. Input data is given by the user directly, adjusting certain parameters of calculations depending on the distance and modes of transportation, as well as the quantities of food products. As far as the Footprint Reporter^{TM} inventory is concerned, it has to be noted that it includes a selection of food collections based on cradle-to-gate LCA models while ready meals are handled separately. In specific, the calculations of the emissions produced by delivery of ready meals depend on distance and mode of transport, as well as the quantities of food. Consequently, large-scale institutional purchases can be included (Wakeland, et al. 2007). The data sources of Footprint Reporter^{TM} inventory include, inter alia, Ecoinvent (Kim et al., 2008).

2.3.3 *Case studies*

Footprint Reporter^{TM} as an off-the-shelf system has been carefully designed in order to help SMEs calculate their GHG emissions and comply with voluntary and mandatory carbon-reporting standards (Langeveld and Routledge, 2014). Some of the best known case studies include the Royal College of General Practitioners, Heritage Lottery Fund and Chicago 2016 Olympic bid (Footprint Reporter^{TM}, 2015).

2.3.4 *Basic advantages / disadvantages*

Advantages

- Details are visible in one view.
- Parameters for the calculation of the carbon footprint are adjustable.

- All quantitative, qualitative and meta data are calculated based on the product (Amani and Schiefer, 2011).
- The required information for the calculation of the carbon footprint is not complex data (RCGP, 2011)
- Footprint Reporter™ is a flexible tool, since a simple approach or a more detailed -if there is information available- are provided (RCGP, 2011).
- Benchmarking assessments are also available, in order to improve efficiency and cut costs (Langeveld and Routledge, 2014).

Disadvantages

- Footprint Reporter™ does not provide GWP results (Footprint Reporter™, 2015).
- The food collections provided bear low level of specificity and high level of aggregation.

2.4 LCD

2.4.1 *Overview*

Table 6 Low Carbon Diet (LCD)

General characteristics of Low Carbon Diet tool	
Tool name	Low Carbon Diet
Developer name	Bon Appétit
General boundaries	Cradle-to-gate (up to distributor)
Language of interface	English
Access/Installation Requirements	Free access www.eatlowcarbon.org

Low Carbon Diet (LCD) calculator has been developed to calculate the GHG emissions produced from the food supply chain (Amani and Schiefer, 2011). The tool is developed by Bon Appétit and is similar to CarbonScope™, as they both depend on the PLCA approach (Amani and Schiefer, 2011).

2.4.2 *Methods / Technical characteristics*

Low Carbon Diet is a cross-sector carbon footprint calculator referring to the production, distribution and preparation of food. Nevertheless, Low Carbon Diet tool is not only a carbon footprint calculator, but also an educational website illustrating general principles of low-carbon eating habits that may affect users' daily behavior:

- ✓ minimization of reliance on red meat and cheese,
- ✓ careful portioning,

- ✓ sourcing of meats, vegetables and non-tropical fruits from North American farms and
- ✓ avoidance of air-freighted seafood.

Online operation of the Low Carbon Diet is simple, depending on the selection of prepared food collections for calculating the total associated GHG emissions in CO_2e grams (Bon Appétit Management Company Foundation, 2010; Kim et al., 2008). The foods provided in the list underlie the menu of Bon Appétit, including prepared foods and raw ingredients (Kim et al., 2008).

Low Carbon Diet methodology is based on cradle-to-grave assessments for selected food collections. Nevertheless, data provision for food collections in such an aggregated form is not consistent with separate handling of delivery, preparation, consumption and disposal on institution basis. Consequently, double-counting of emissions from the various stages may occur. Therefore, while generalizing delivery distances is a user friendly feature, it does not provide customization of the tool for individual institutions (Bon Appétit Management Company Foundation, 2010).

As far as the food models are concerned, the Low Carbon Diet Calculator uses secondary process data to model cradle-to-gate food emissions, which occur along the life cycle of the product up until to retail. In this context, supply chain management software and other methods were used to compute emissions from the final stages of preparation and delivery. The database depends mostly on European food models, due to the lack of data regarding the US food production chain (Kim et al., 2008). Nevertheless, US data were used in some cases, such as the North American seafood, as well as the electricity generation processes (for highly processed items and bananas only transportation emissions were available) (Scholz et al., 2008).

The tool outputs include all the associated emissions, except for nitrous oxide and methane from food waste (Bon Appétit Management Company Foundation, 2008; Kim et al., 2008). The methodology behind the calculations of the delivery emissions depending on the general national and international distribution chains is based on the CargoScope software. Certain food collections, such as seafood were assumed to have originated from default locations. Apart from the location, seasonality was one of the parameters also considered (i.e. certain season fruits were assumed to have been air-freighted from South America) (Bon Appétit Management Company Foundation, 2008; Scholz et al., 2008; Kim et al., 2008).
As far as the cooking and storage emissions are concerned, the metric used relies on the most commonly used commercial types of cooking appliances. Data required for the design of the

Calculations accounted for the mass of foods per volume (for storage and delivery) as well as energy use for various appliances based on data from the Food Service Technology Center and Energy Star (Bon Appétit Management Company Foundation, 2008; Scholz et al., 2008; Kim et al., 2008).

2.4.3 *Case studies*

Low Carbon Diet is not only a carbon footprint calculator but also a tool that focuses on environmental awareness. Therefore, the tool focuses on individuals, in order to disseminate low carbon eating habits (Bon Appétit Management Company, 2015).

2.4.4 *Basic advantages / disadvantages*

Advantages

- The tool includes well organized food categories (Amani and Schiefer, 2011).
- The different transportation routes are based on origins depending on the data available (Kim et al., 2008).
- The Bon Appétit Management Company Foundation has included life cycle models of 60 ready meals and raw ingredients (Scholz et al., 2008; Kim et al., 2011).
- In order to avoid double calculation of emissions, Low Carbon Diet has included –as far as possible- disaggregated life cycle process data (Scholz et al., 2008; Kim et al., 2011). In this framework, outputs may be useful input material for the development of other carbon accounting tools (Kim et al., 2008).

Disadvantages

- The food collections available are of high aggregation, thus forbidding the separate calculation of the emissions of each stage (e.g. delivery, consumption, disposal etc).
- Double counting due to the high aggregation of data is also possible (Amani and Schiefer, 2011).
- The generalization of delivery data does not allow tool customization for institutes (Amani and Schiefer, 2011).

2.5 *Cool Climate Carbon Footprint Calculator*

2.5.1 *Overview*

Table 7 Cool Climate Carbon Footprint Calculator

General characteristics of Cool Climate Carbon Footprint Calculator	
Tool name	Cool Climate Carbon Footprint Calculator
Developer name	Renewable and Appropriate Energy Laboratory (RAEL) of the Berkeley Institute of the Environment
General boundaries	Cradle-to-gate

Language of interface	English
Access/Installation Requirements	Free access http://coolclimate.berkeley.edu/ http://www.coolcalifornia.org/business-calculator

Cool Climate Carbon Footprint Calculator aims at the calculation of indirect GHG emissions for an individual consumer or per household. The tool has been designed based on the Economic Input-Output Life Cycle Assessment (EIOLCA), which has been developed by Green Design Institute at Carnegie Mellon University and the Comprehensive Environmental Database Archive (Jones and Kammen, 2011).

2.5.2 *Methods / Technical characteristics*

The tool methodology is based on the amount of money (in specific, US dollars) spent by the user-consumer on his/her daily expenditures, such as clothing, food, services etc. More specifically, the tool accounts the final emissions of the user's daily consuming habits based on the money spent for purchasing their products. The emissions are quantified in tons of CO_2 produced per year.

In regard to the food category, the calculator comprises six (6) main food groups:

- Meat
- Fish and eggs
- Fruits and vegetables
- Cereals and bakery products
- Dining out
- Rest (e.g. snacks, drinks etc)

User input data requested are the food category and the amount of money spent on each category. Based on the food category and the US dollars spent on, associated amounts of GHG emissions are calculated. Some of the features encompassed within the tool are the comparison of the user's results to typical households in their region, or to households of similar size and income (Jones, 2005; Kim et al., 2008; The Berkeley Institute of the Environment, 2015).

It has to be noted that CoolClimate tool incorporates a small number of large food categories, in order to simplify the calculation process. Nevertheless, the complete EIOLCA database has many more distinctions and categories to choose from. More specifically, for the purposes of the carbon calculator, EIOLCA aggregates emissions into three main categories, namely: transportation, facilities (energy, waste and construction) and procurement. The calculator allows users to adjust emissions based on 20 different expenditures categories (different categories for each business based on the largest contributor) (Jones and Kammen, 2014). This broad aggregation is considered as the main limitation of this calculator, since GHG emissions might vary in the food sector due to the different production methods. A lack of coverage of these differences could lead to a wrong impression about the real amount of GHG emission produced (Kim et al. 2008; The Berkeley Institute of the Environment, 2015).

2.5.3 *Case studies*

Cool Climate Carbon Footprint Calculator has been designed for households, businesses, local governments and non-governmental organizations. Depending on the tool, various features are provided. CoolClimate Carbon Footprint Calculator with Community support refers to individuals and households, in order to calculate their carbon footprints. Indicatively, the features provided include comparisons of carbon footprints amongst households of similar size, location and income. As far as CoolClimate Carbon Footprint Calculator for small businesses is concerned, defaults based on several crucial parameters are provided in order to compute carbon footprint from all business expenditures shortly (Kim et al., 2008; The Berkeley Institute of the Environment, 2015).

2.5.4 *Basic advantages / disadvantages*

Advantages

- Shortages of the CoolClimate inventory can be supplemented by EIOLCA database, which is available free online (Kim et al., 2008).
- Although the CoolClimate Carbon Footprint Calculator offers a small number of food categories, EIOLCA on the whole offers a more comprehensive selection of food industry subsectors (Kim et al., 2008).
- User friendly input data requirements.

Disadvantages

- The tool provides high aggregation by using a small selection of broad food categories (Amani and Schiefer, 2011).
- The tool lacks in specificity, due to the differences in production methods that are not taken under consideration for the calculation of the carbon footprint.
- The tool is not process-based.
- Results based on generalizations make input data less demanding for the users, but nevertheless fail to capture important differences (e.g. in this case the differences amongst the various food types, or for EIOLCA the differences of the various production methods) (Amani and Schiefer, 2011; Kim et al., 2008).
- The CoolClimate Carbon Footprint Calculator with Community support refers to individuals, therefore the input data depend on the amount of money spent by the user. EIOLCA inventory is based only to the fraction of consumer dollars received by the manufacturing industries in order to assess the emissions from manufacturing (Hendrickson et al., 2006; Jones and Kammen, 2011). In this framework, a conflict in the inventories may appear.

2.6 FoodCarbon Footprint Calculator

2.6.1 Overview

Table 8 FoodCarbon Footprint Calculator

General characteristics of FoodCarbon Footprint Calculator	
Tool name	FoodCarbon Footprint Calculator
Developer name	Carbon Footprint Ltd
General boundaries	Cradle-to-grave
Language of interface	English
Access/Installation Requirements	Free access http://www.foodcarbon.co.uk/calculator.html

The FoodCarbon Footprint Calculator assesses the carbon footprint as a result of production, packaging and transport of food. The tool targets individual consumers and has been designed in order to illustrate the environmental impact of daily activities. The methodology followed for the development of the calculator is based on emission factors either country-specific or international (Amani and Schiefer, 2011).

2.6.2 Methods / Technical characteristics

FoodCarbon Footprint Calculator has been developed based on the methodology suggested by defra's Voluntary Reporting Guidelines. There are several more emission factors used, such as a selection of factors from the GHG protocol adjusted to the location under consideration.

The tool calculates the CO_2 emissions depending on the annual consumption per food product (Kim et al., 2008). More specifically, the calculator provides a list of daily food purchases encompassed by data for the quantities, origin and production method (i.e. organic or conventional, chilled versus fresh etc). Both direct and indirect emissions are assessed with the tool. The calculations for direct emissions are based on conversion factors from several sources, such as defra, World Resources Institute (WRI) GHG Protocol, Vehicle Certification Agency (VCA), UK, US Environmental Protection Agency (EPA), US Department of Energy (DOE), Green House Office of Australia, Standards Association GHG Registries of Canada (Carbon Footprint Ltd, 2015). On the contrary, the indirect emissions are based on estimates developed by Carbon Footprint Ltd (Carbon Footprint Ltd, 2015). The main reason for this different approach is the fact that the main scope of the tool is to illustrate the environmental impact of the daily activities of the users and not to provide precise calculations of the secondary emissions (Amani and Schiefer, 2011).

The final emissions calculated are carbon (carbon dioxide and methane) or expressed in carbon equivalents CO_2e (e.g. nitrous oxide) per year (Kim et al., 2008).

2.6.3 *Case studies*

The FoodCarbon Footprint tool focuses on the environmental awareness, illustrating the impacts of the our daily food choices (Kim et al., 2008). The adoption of a "basket" of the most frequently purchased foods according to the consumption patterns of the UK households reflects the target audience of the tool. Therefore, the main users of the FoodCarbon Footprint calculator are individual users.

2.6.4 *Basic advantages / disadvantages*

Advantages

- The tool includes food production methods, as well details regarding the quantities and origin, contributing to elevate the specificity of the tool.
- The calculator uses emission factors and conversion factors based on official and international standards.
- Developers put emphasis on the selection of frequently purchased food products according to the consumption patterns recording in the UK households (FoodCarbon, 2015).

Disadvantages

- The calculator is based on the initial questionnaire for the users. Therefore, product based comparisons are not facilitated (Kim et al., 2008).
- The tool inventory underlies data only for the UK.
- The final emissions are calculated based on input data regarding annual food consumption that may result in false assumptions (Kim et al., 2008).
- Since the main scope of the tool is to illustrate the environmental impacts of the users' daily food purchases, the amounts of the final emissions may not be precisely close to reality (Amani and Schiefer, 2011).

2.7 CLA CALM

2.7.1 *Overview*

Table 9 CLA CALM

General characteristics of CLA CALM calculator	
Tool name	CLA CALM
Developer name	Country Land and Business Association (CLA) working in partnership with Savills. The latest upgrade is sponsored by Natural England whilst the original calculator was produced with the support of the East of England Development Agency (EEDA) and the Crown Estates.
General boundaries	Farm and land use

Language of interface	English
Access/Installation Requirements	Free web-based calculator http://www.calm.cla.org.uk/

The CLA CALM calculator is a GHG calculator for farmers and land managers. Measurements include both direct emissions of farm activities (e.g. livestock emissions) and indirect emissions (e.g. feed and fertilizer inputs), as well as the carbon balance (emissions against sequestration).

It should be noted that this calculator uses 2005 UK national GHG emissions methodology (Choudrie et al., 2008), following the IPCC 2001 guidance on Tier 1. In addition, guidelines by defra and the GHG Protocol Corporate Accounting and Reporting Standard have also been considered (Denef et al., 2012).

2.7.2 *Methods / Technical characteristics*

The cross-sector tool CLA CALM provides measurements regarding the emissions of CO_2, CH_4 and N_2O of activities in farms/estates in balance against carbon sequestration. The input data required include information regarding the farm area, energy use, fertilizers used, livestock, cultivation, horticulture, land-use changes and forestry (Denef et al., 2012).

Except for 2005 UK national GHG emissions methodology, the tool follows the GHG Protocol Standard by adopting (Holmes and Metcalfe, 2008):

- Scope 1 for the calculation of the direct GHG emissions from the combustion of fuels in vehicles in the farm, livestock and their waste, as well as from cultivation.
- Scope 2 for accounting indirect GHG emissions from e.g. the generation of electricity.
- And Scope 3 that is associated with the determination of the emissions produced from manufacturing of fertilizers and feeds.

The tool also uses IPCC 2001 guidance on Tier 1, where modifications have been made only to manure and livestock, as well as on milk yield class (Denef et al., 2012). In specific, the emissions associated with the organic manure refer only to the amounts used to the farm under consideration. In the contrary, the national manure calculations are based on livestock members. One more modification has been made by the developers regarding the livestock emissions, which are not based on the ownership of the stock but where the animals graze. Furthermore, the tool users can choose a milk yield class instead of the national average yield figure (Holmes and Metcalfe, 2008; Amani and Schiefer, 2011).

In this context, CLA CALM calculator complies with the national guidelines for the measurement of GHG emissions. Therefore, if farms choose to compute their carbon footprint with this tools, the figures could add up to the total national emissions calculated for agriculture, land use changes and forestry (Holmes and Metcalfe, 2008).

As far as the inventory of the CLA CALM tool is concerned, it has to be noted that it has been updated with the latest UK National Inventory Report. Finally, there is no clear evidence regarding the inclusion of a decision support tool in the CLA CALM calculator, but as it is clearly stated in the guidebook of the calculator: one of the main purposes of the tool is to disseminate the concept of carbon balance in farm businesses and highlight some applicable measures regarding the reduction of GHG emissions in farms (Denef et al., 2012).

2.7.3 *Case studies*

The calculation of GHG emissions results in cost savings, which possibly would not have been revealed in other ways (CLA CALM calculator, 2015). In this framework, CALM calculator has been used so far in the Natural England Carbon Baseline Survey Project (Holmes-Ling and Metcalfe, 2008; Denef et al., 2012), that used a sample of 200 farms in the United Kingdom (Denef et al., 2012).

2.7.4 *Basic advantages / disadvantages*

Advantages

- It is a calculator that uses three scopes in processes to describe emissions arising from a business.
- The tool includes organic/conventional distinction of farming methods used.
- The tool is a business-based calculator that shows the balance amongst annual emissions, therefore sequestration is considered in the calculations. Sequestration is a critical parameter for accounting GHGs in land-based businesses (Kim et al., 2008).
- The CALM Tool is recommended for whole-farm assessments (Whittaker et al., 2013).
- The CALM calculator has been designed to account emissions produced directly by the activities of the farm (CLA CALM calculator, 2015). Consequently details regarding the production methods are under consideration, contributing to a higher level of specificity (Denef et al., 2012).
- The tool follows the methodology used to prepare the national inventory. In this framework, double counting of the sectors' emissions is avoided (CLA CALM calculator, 2015).
- CLA CALM accounts emissions specifically for the farm business and does not incorporate stages upstream or downstream of the farm (CLA CALM calculator, 2015).

Disadvantages

- Food categorization is not available.
- The CALM Tool does not state the specific source of calculations (Whittaker et al., 2013).

- Due to the high level of specificity, the tool operation is quite complex. Therefore, the tool is recommended for use by professional agricultural consultants and scientists (Denef et al., 2012).

2.8 CCalc

2.8.1 *Overview*

Table 10 Carbon Calculations over the life cycle of industrial activities (CCalc)

General characteristics of CCalc calculator	
Tool name	CCalc
Developer name	The CCaLC Carbon Footprinting Tool has been developed by a research group at the University of Manchester, as part of a project funded by the Carbon Trust, EPSRC and NERC under the 'Carbon Vision Industry Programme.
General boundaries	Diesel consumed, fertilizer manufacture, seeds, pesticides, purchased electricity (on farm), manure delivery, transport, final distribution, land use change.
Language of interface	English
Access/Installation Requirements	Free of charge/ All versions require windows (XP or newer) and some versions require also Microsoft excel http://www.ccalc.org.uk

The CCalc tool calculates carbon footprint, water footprint, as well as other environmental impacts. In addition, the optimization of carbon footprints is also available with this tool. The calculator focuses on food and drink, bio-feedstocks, biofuels and chemicals and related products. CCalc uses the internationally accepted life cycle methodology as defined by ISO 14044 and PAS2050.

2.8.2 *Methods / Technical characteristics*

The cross-sector tool CCalc includes actual calculations for the carbon footprint of different industrial sectors along their complete supply chain (CCalc, 2015).

The tool follows a life cycle methodology for an integrated environmental and economic analysis of carbon emissions in different industrial systems. The main feature refers to the carbon-equivalent estimations, however several other environmental impacts can be assessed too. As far as the methodology used for estimating the economic impacts along the supply chains, investment and operating costs have been assessed in order to value the flows of materials and energy in the supply chain. In this framework, optimisation techniques have also been included for identifying the optimum low-carbon material, product and technological options. This tool feature is based on the solver function of the Microsoft excel program.

The assessments underlie on three databases, namely CCaLC, Ecoinvent and User database. The CCaLC database consists of publicly available data and data generated during the course of tool development. Furthermore, the Ecoinvent database is a proprietary database that is included in the CCaLC tool with a kind permission of Ecoinvent, while User database is created and populated by the user.

It has to be noted that a multi-criteria decision analysis (MCDA) is also available to help manage and trade-off different environmental and economic criteria. Some of the basic tool features are: the basis and time scales for analysis, the system boundaries, recycling and "cascading", allocation, carbon sources and sinks, integration of environmental and economic data and data availability, transparency and uncertainty (CCalc Position Paper, 2015).

2.8.3 *Case studies*

The target users of CCaLC tool are industry and policy makers. Indicatively, some of the case studies used as sample for the optimization of the tool refer to several industrial sectors, namely: (i) chemicals and related products, (ii) bio-feedstocks, (iii) food and drink and (iv) biofuels (CCalc, 2015).

2.8.4 *Basic advantages / disadvantages*

Advantages

- Easy, user-friendly tool for calculating the carbon footprint and other environmental impact categories of a product.
- The tool comes with a comprehensive support and guidance instructions (Whittaker et al., 2013).

Disadvantages

- The applied optimisation function uses deterministic techniques, and hence, the optimum value is always affected by the initial value of the optimization problem.
- The tool provides low level of specificity regarding the assessments of N_2O emissions from soil (Whittaker et al., 2013).

2.9 Organic Farmers Carbon Calculator

2.9.1 *Overview*

Table 11 Organic Farmers Carbon Calculator

General characteristics of Organic Farmers Carbon Calculator	
Tool name	Organic Farmers Carbon Calculator

Developer name	Climate Friendly Food (CFF)
General boundaries	Wheat Yield, Diesel Consumed, N2O emissions from residues (ploughed in), Farm machinery, Purchased Electricity (on farm), Manure delivery, Transport, Final Distribution, Land use change, Straw Yield, Sequestration in farm features .
Language of interface	English
Access/Installation Requirements	Free of charge/ no installation required, as it is an on-line tool. http://cffcarboncalculator.org.uk/carboncalc

The Organic Farmers Carbon Calculator is a free, web-based farm management tool that enables the identification of a farm's total annual emissions. The software uses its own methodology and refers only to carbon footprint calculation –i.e. no further LCA is possible.

2.9.2 *Methods / Technical characteristics*

Organic Farmers Carbon Calculator is a sector-specific tool. This tool focuses on environmental awareness illustrating the impacts caused by the GHG emissions, as well as the adoption of practices for evaluating the quality of soils (Whittaker et al., 2013). More specifically, one of the main targets of the tool is to point the hotspots of a farm and measure the GHG emissions produced. In this framework, the operations with the most significant emissions are identified, and mitigation measures are proposed. In addition, the tool has been designed to help farmers to take further actions on their farms to reduce carbon footprint.

This carbon calculator uses a broader scope to a whole farm calculation, taking into account sequestration and embedded emissions (i.e. in farm machinery and building/infrastructure materials) to a greater extent. A report is produced displaying the results of the calculation indicating the level and type of emissions attributable to the various areas of the farming system. The final emissions calculated indicate the annual whole farm emissions in CO_2 equivalent, as well as the total emissions of CH_4, N_2O and CO_2.

Finally, it is mentioned that the calculator's inventory uses data from over 30 sources including the IPCC 2006 and defra GHG Conversion factors.

2.9.3 *Case studies*

A number of case studies related to carbon calculation on different farms towards more sustainable practices have been already conducted with the Organic Farmers Carbon Calculator. An indicative list of case studies is available online (e.g. East Hendred Farm, Oxfordshire, Woodland Valley Farm, Cornwall etc) (Farm Carbon Calculator, 2015).

2.9.4 *Basic advantages / disadvantages*

Advantages

- No downloading is necessary as it is an on-line calculator.
- Very easy to use interface and useful guidance and support material provided (Whittaker et al., 2013).
- It is one of the few tools that have included the emissions produced from animal manure since they are usually minor depending on the quantities used (Whittaker et al., 2013).

Disadvantages

- No other impact categories are possible to assess apart from climate change.
- Lack of transparency is identified, therefore there is no way to explain the lower estimations regarding the GHG emissions produced (Whittaker et al., 2013).
- There is low level of specificity, since the N fertilizer manufacture and N_2O emissions from soil have not been taken under consideration (Whittaker et al., 2013).
- There is an overestimation of the GHG emissions from the manufacture of farm machinery, since the tool account the emissions produced over an unspecified time period and not for one year's operation (Whittaker et al., 2013).

2.10 CFT v1.1

2.10.1 *Overview*

Table 12 Cool Farm Tool v1.1 (CFT v1.1)

General characteristics of Cool Farm Tool v1.1	
Tool name	Cool Farm Tool v1.1
Developer name	Cool Farm Institute (CFI) by the Centre for Agriculture and Environment and Best Foot Forward
General boundaries	Wheat Yield, Diesel Consumed, Fertiliser N_2O (total figure), Fertiliser manufacture, N_2O emissions from residues (ploughed in), Manure N_2O (direct and indirect), Pesticides, Purchased Electricity (on farm), Transport, Final Distribution, Land use change, Straw Yield, Sequestration in farm features, Lime
Language of interface	English
Access/Installation Requirements	There is a free of charge version. Cost per annum is needed for the rest versions/ It needs Microsoft excel. http://www.coolfarmtool.org

The Cool Farm Tool refers to the calculation of carbon footprint covering a broad range of farming systems. The software follows the internationally accepted life cycle methodology as defined by ISO 14044 and PAS2050 (Cool Farm Tool, 2015).

2.10.2 *Methods / Technical characteristics*

The Cool Farm Tool is a sector-specific tool that has been designed from the University of Aberdeen by Unilever in 2009, and was originally released in April 2010 (Sustainable Food Lab, 2015). The main scope of the tool is the precise calculation of GHG emissions by using data that are available to (or easily obtainable by) the average farmer, supply chain managers and companies (Denef et al., 2012). The metric used evaluates the GHG emissions and soil carbon sequestration changes depending on management activities (Denef et al., 2012). Therefore, the tool provides information to farmers regarding possible modifications in their high-carbon management practices.

In specific, the tool calculates the greenhouse gas balance of farming including emissions from fields, inputs, livestock, land use and land use change, as well as primary processing.

The methodology used depends on IPCC Tier 2, providing a simple approach for reducing the carbon footprint in farms (Sustainable Food Lab University of Aberdeen and Unilever plc, 2011). And as it is suggested, the higher Tier IPPC approach adopted, the higher reduction is accomplished in the results compare to using IPCC defaults (Guo et al., 2011). IPCC methodology is also followed in this tool in order to model specific land use changes for over 113 countries (Hillier et al., 2011). Finally, it is noted that it incorporates calculations regarding soil carbon sequestration (Denef et al., 2012) depending on specific soil parameters and soil fertilizer types (Hillier et al., 2011).

2.10.3 *Case studies*

According to the report submitted for the project "Technical Guidelines and Scientific Methods for Entity-Scale Greenhouse Gas Estimation" (Denef et al., 2012), the tool was foreseen to be used by Unilever as part of its Metric Reporting requirements of its Sustainable Agriculture Code and also in a multi-company project on agricultural climate mitigation coordinated by the Sustainable Food Lab, including several multinational companies (e.g. Pepsico, Heinz, Sysco, Ben & Jerry's, Heineken, Marks & Spencer etc) (Sustainable Food Lab, 2015). Indicatively, Cool Farm Tool has been applied in the following case studies:

- The effects of coffee production on climate change.
- The effects of climate change on smallholder farmers in Guatemala producing frozen vegetables for export.
- The comparative analysis of five leading farms to identify key emission sources and possible GHG emissions reduction pathways for tomato cultivation.

- A program designed to spur reductions in greenhouse gas emissions in organic eggs production.

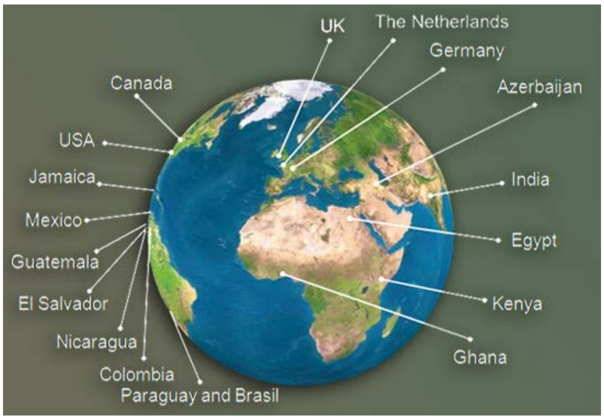

Figure 2: Locations that the Cool Farm tool has been implemented (Sustainable Food Lab, 2015)

2.10.4 *Basic advantages / disadvantages*

Advantages

- It provides results in various formats, as well as all the emission sources (Whittaker et al., 2013).
- It permits the user to access referenced sources of the emission factors used.
- The tool comes with a user-friendly interface and support and guidance material.
- There is high level of transparency, since users are able to check the original calculations (Whittaker et al., 2013).
- Cool Farm Tool is considered as one of the most comprehensive online tools, since it includes parameters regarding land-use changes and follows Tier 2 IPCC methodology (Whittaker et al., 2013).
- Cool Farm Tool is a calculator that is suitable for the assessment of a single crop or a single crop farm (Whittaker et al., 2013).
- It is a high specificity level calculation tool for land use changes in tillage, inputs and residue management (Whittaker et al., 2013).
- The tool provides precise calculations for land use changes by offering the easiest template for a non-expert user (Whittaker et al., 2013).

Disadvantages

- Since it is a tool that suitable for single crop or single crop farm assessments, the input data required are of high specificity.

2.11 Muntons barley calculator v4

2.11.1 Overview

Table 13 Muntons barley calculator v4

General characteristics of Muntons barley calculator v4	
Tool name	Muntons barley calculator v4
Developer name	University of Aberdeen, University of East Anglia, NIAB-TAG and Muntons
General boundaries	Wheat Yield, Diesel Consumed, Fertiliser manufacture, Seeds, Pesticides
Language of interface	English
Access/Installation Requirements	Free of charge/Download and use in microsoft excel. http://www.muntons.com/

Muntons barley calculator v4 accounts the carbon footprint of malting and other related processes, considering electricity and water consumption. This carbon footprint model has been developed with the Centre for Low Carbon Futures and based on the ECOINVENT database for farming activities.

2.11.2 Methods / Technical characteristics

The Maltsters Association of Great Britain (MAGB) has deployed an analytical method based on PAS2050 guidelines that is useful to assess carbon emissions in malting (MAGB, 2011). The methodology used was further enhanced by the Stockholm Environmental Institute at the University of York (Davies, 2011).

The tool targets on farmers (Whittaker et al., 2013), therefore the input data required are for standard site inputs (while emissions from urea manufacture are not required) (Whittaker, 2013). The emission calculations result per tonne of grain based on nine high-carbon emission elements in crop cultivation. In this context, the users are able to identify the most effective methods to implement in order to reduce GHG emissions from farming (Whittaker, 2013). By using the tool, users comprehend the major contributors to the footprint, such as nitrogen (N) fertilizers, yield, tractor running hours, pesticide use and seed.

As far as the inventory is concerned, the tool uses the Ecoinvent database and a model developed by the Centre for Low Carbon Futures. In specific, the Stockholm Environment Institute assigned the ECOINVENT database in order to generate the carbon data (Davies, 2011).

2.11.3 *Case studies*

The tool has been used in cases for calculating the carbon footprint of malting barley. The main aim of the tool is to provide as carbon efficiently as possible good quality malting barley from the farmer to the brewer (Davies, 2011).

2.11.4 *Basic advantages / disadvantages*

Advantages

- It is easy to use with a friendly interface. It can be used from everyone as it does not require extensive knowledge on carbon footprint assessments.

Disadvantages

- This calculator is not intended to be a whole farm model as it does not include details on land use change (Whittaker et al., 2013).
- The final emissions are delivered with a single figure per tonne of crop, without a breakdown of all emission sources *(*Whittaker, 2013).
- Since Muntons is a single-crop carbon calculator, the information required is on all site inputs attributed to a single crop (Whittaker et al., 2013).

2.12 Biograce calculator v4b

2.12.1 *Overview*

Table 14 Biograce calculator v4b

General characteristics of Biograce calculator v4b	
Tool name	Biograce calculator v4b
Developer name	An outcome of the BioGrace project (Biofuel Greenhouse gas emissions: Align Calculations in Europe) involving the following partners: Agence de l'environnement et de la maitrise de l'energie (ADEME), France Bioenergy 2020+ GmbH (BE2020), Austria Bio Intelligence Service (BIO IS), France Research Centre for Energy, Environment and Technology (CIEMAT), Spain Energy, Management and Information Technology Consultants S.A. (EXERGIA), Greece Institute for Energy and Environmental Research (IFEU), Germany Swedish Energy Agency (STEM), Sweden.
General boundaries	Wheat Yield, Diesel Consumed, Fertiliser N2O (total figure), Fertiliser manufacture, N2O emissions from residues (ploughed in), Manure N2O (direct and indirect), Seeds, Pesticides, Transport, Final Distribution, Land use change
Language of interface	English
Access/Installation Requirements	Free of charge / Excel based GHG calculation tool. http://www.biograce.net/home

The tool performs calculations of biofuel GHG emissions combined with other schemes (obligatory or voluntary) in compliance with the Renewable Energy Directive (2009/28/EC, RED) and the Fuel Quality Directive (2009/30/EC, FQD) (Biograce, 2015). Biograce is a useful tool for economic operators since it highlights the RED default values and calculations (Neeft et al., 2012).

2.12.2 *Methods / Technical characteristics*

Biograce calculator v4b is a sector-specific tool that includes one separate excel worksheet for each of the 22 biofuel pathways. The objective of the tool is twofold based on the service of two separate actions. Firstly, the tool aims to highlight the GHG calculations that led to the values included in the RED Annex V, and secondly to allow the tool-users to conduct calculations (Neeft et al., 2012). In this framework, the biofuel producers can either replicate the Joint Research Center (JRC) input values with an accuracy of about 0,05 g $CO_{2.eq}/MJ_{biofuel}$ or accounting their own GHG balance by importing data regarding yields, amounts of fertilizer and process energy, transport distances etc (Whittaker et al., 2013).

The tool incorporates a list of additional standard values with data for selections of mineral fertilizer types and other inputs in farming, conversion inputs (e.g. process chemicals), national electricity grids, solid and gaseous biomass sources for energy and transport (pipeline). All of the additional data have been retrieved from the "E3database", and are the exact same values that the JRC supplied the Commission with, for determining the RED Annex V GHG default values (Biograce, 2011).

2.12.3 *Case studies*

The BioGrace project ran from 2010 to 2012 and was financed by the Intelligent Energy Europe programme for the harmonization of biofuel calculations. Therefore, its main target audience is comprised by biofuel producers. Currently, the project is managed by the Institute for Energy and Environmental Research with one of the former project partners. The recognition received, is valid until June 2018 (Biograce, 2015).

2.12.4 *Basic advantages / disadvantages*

Advantages

- The BioGrace tool allows its users to replicate RED values and make their own calculations.
- It is easy to use with a friendly interface. It can be used from everyone as it does not require extensive knowledge on carbon footprint assessments.
- The BioGrace tool is meant to be used in combination with other similar schemes that cover the origin of raw materials (Biograce, 2015).

- Since BioGrace was initially deployed in response to the introduction of the RED legslation, the demands are already high in terms of accurate reporting and hence the tool is highly informative, transparent and comprehensive (Whittaker et al., 2013).
- The methodology used in the RED legislation is in full compliance with the calculation methodology in the Biograce tool (Whittaker et al., 2013).
- Biograce tool is recommended for biofuel GHG accounting in compliance with RED legislation (Whittaker et al., 2013).

Disadvantages

- Although the BioGrace GHG calculation tool has been recognised as a voluntary scheme by the European Commission (according to the sustainability criteria of the Renewable Energy Directive 2009/28/EC Article 18 4-6, 17 2, Annex V and the Fuel Quality Directive 2009/30/EC), a recently published comparative analysis of similar tools revealed the production of different results (Hennecke et al., 2012; Whittaker et al., 2013). The differences regarding the different estimations for land use change, and in particular for conversion of forestland, are based on the different emission factors used for fertilizer manufacture and N_2O emissions from soil (Hennecke et al., 2012).

2.13 RFA-RTFO Carbon Calculator v1.0

2.13.1 *Overview*

Table 15 RFA-RTFO Carbon Calculator v1.0

General characteristics of RFA e RTFO Carbon Calculator v1.0	
Tool name	Renewable Fuel Agency (RFA)- Renewable Transport Fuel Obligation (RTFO) Carbon Calculator v1.0
Developer name	Department for Transport, Great Minster House, UK
General boundaries	Wheat Yield, Diesel Consumed, Fertiliser N_2O (total figure), Fertiliser manufacture, Pesticides, Purchased Electricity (on farm), Transport, Final Distribution, Land use change
Language of interface	English
Access/Installation Requirements	Free of charge/ Download as a separate software. There is no mention regarding system requirements. http://www.dft.gov.uk/publications/carbon-calculator

The UK and Ireland Carbon Calculator software (RFA-RTFO) has been developed on order to calculate GHG emissions of companies for submission of monthly carbon and sustainability reports (RTFO 1.3) to the RTFO Administrator. The main objective of the software is to accept data directly from the supply chain for calculating the GHG emissions of a company.

The tool can also provide calculations where there is lack of actual data and fuel chain default values are used (DfT and E4tech consulting, 2015).

2.13.2 *Methods / Technical characteristics*

The tool complies with the Directive 2009/28/EC of the European Parliament and of the Council on the promotion of the use of energy from renewable sources. More specifically, version 7.1 of the tool uses the LCA methodology (which is in compliance with the RED and the amendments) and the RTFO Carbon and Sustainability Guidance.

The methodology followed for the estimation of the biofuel carbon intensity by the RFA-RTFO calculator depends on the year the user selects to make the carbon and sustainability report. In specific, if the year is before 2009 accounting is performed based on the Carbon and Sustainability Guidance for RTFO year 1 and 2; if the year is 2010, calculations are conducted according to the European methodology as described in the European Renewable Energy Directive of 2009 and the RTFO Carbon and Sustainability Guidance Year Three; if the year is 2011 or after, the methodology followed is based on the European methodology for both fuel chain emissions and land use change emissions as described in the RED.

Finally, it is worth mentioning that the interface is user friendly since the data required for computing the fuel carbon intensity are imported using graphical representation of a biofuel supply chain (DfT and E4tech consulting, 2015).

2.13.3 *Case studies*

The use of the RFA-RTFO calculator is based on a system of voluntary targets, therefore the number of verified reports submitted is different from year to year. Indicatively, some of the companies associated with the fuel production that have submitted carbon and sustainability reports by using the RFA-RTFO calculator are Greenergy, LLissan, Mabanaft, Topaz, Esso, Harvest, Petroplus, Shell, ConocoPhillips, BP, Chevron, INEOS, Morgan Stanley and Murco (Renewable Fuels Agency, 2011).

2.13.4 *Basic advantages / disadvantages*

Advantages

- The methodology followed in the RFA-RTFO tool is in compliance with RED guidelines.
- RFA-RTFO tool helps biofuel producers to account their GHG emissions balance in response to RED reporting methodology (Whittaker et al., 2013).

Disadvantages

- The tool has specifically been developed to be used in the UK and Ireland.

- The tool lacks in comprehensiveness, since it does not provide different options regarding fertilizers and does not include N_2O in crop residues (Whittaker et al., 2013).

2.14 BEAT2

2.14.1 Overview

Table 16 Biomass Environmental Assessment Tool (BEAT 2)

General characteristics of BEAT 2 tool	
Tool name	Biomass Environmental Assessment Tool BEAT2
Developer name	Developed by AEA and North Energy Associates for defra and the Environment Agency
General boundaries	Wheat Yield, Diesel Consumed, Fertiliser N_2O (total figure), Fertiliser manufacture, N_2O emissions from residues (ploughed in), Seeds, Farm machinery , Pesticides, Purchased Electricity (on farm), Manure delivery, Transport, Final Distribution, Straw Yield
Language of interface	English
Access/Installation Requirements	Free of charge/ download software This software requires MS Access 2000 or later, Excel 2000 or later and Adobe Acrobat. www.biomassenergycentre.org.uk/

The main objective of BEAT2 tool is to help users assess the potential environmental benefits and impacts of bioenergy technologies (Biomass Energy Centre, 2015). This LCA software assesses all impacts and benefits on a every stage of a biofuel supply chain, from production and cultivation of feedstock to conversion to liquid biofuel including transport and processing steps (Bates, 2015). In this framework, the user can decide how detailed the input data will be. Therefore, the tool also provides default parameters, which many of them can be altered by the user (Forest Research, 2015).

2.14.2 Methods / Technical characteristics

This cross-sector GHG calculator focuses on biomass plants for: electricity production, combined heat and power (CHP), heat (industrial and domestic boilers), anaerobic digestion (heat, electricity and CHP) and liquid biofuels, such as bioethanol and biodiesel. The tool comes with a full set of default data (considering typical values for biomass yields, and generating efficiencies) in order to provide easy examinations of typical bioenergy schemes.

In specific, six main conversion routes for Bioenergy are covered with a separate excel workbook: (i and ii) biomass-fuelled power plant (with or without heat) for the production of electricity using grate combustion, gasification or pyrolysis, (iii) biomass-fuelled heating boilers, (iv) co-firing of biomass in existing large power plant, (v) anaerobic digestion and combustion of biogas for producing electricity and/or heat in small scale, on-farm plant and in centralised anaerobic digestion, (vi) production of liquid biofuels.

The BEAT2 database is organised in a set of workbooks, providing a comprehensive evaluation of the whole chain of primary energy inputs and GHG for the biomass energy technologies. Nevertheless, there are certain limitations regarding constraints on life cycle assessment as a practical technique, uncertainties in the data, changes in the data due to technology and variations over time (AEA Energy & Environment and North Energy, 2008).

2.14.3 *Case studies*

BEAT2 calculator has been used in case studies from the Forestry Commission and government agencies (e.g. Barnsley Biomass, Beaverwood Products, Bwlch Nant yr Arian, Highside Timber Ltd, Ripon etc), as well as in projects from regional and other organizations (e.g. Woodfuel boiler map 2010, RHI Installations Report etc). There are also examples from commercial installers and manufacturers who have calculated their GHG emissions with BEAT2 tool (such as Eco-Exmoor Devon case studies, Energy Innovations case studies etc), as well as biomass power stations, liquid biofuels plants, and anaerobic digestion and biogas plants (Biomass Energy Centre, 2015).

2.14.4 *Basic advantages / disadvantages*

Advantages

- The BEAT Tool allows the users to access the original Excel-based calculations, including referenced sources of emission factors (Whittaker et al., 2013).
- BEAT includes some aspects of uncertainty (Whittaker et al., 2013).
- BEAT2 allows the user to import data on different categories of bioenergy conversion plant and feedstock (Forest Research, 2015).
- The tool is detailed and offers transparency (AEA Energy & Environment and North Energy, 2008).

Disadvantages

- BEAT2 is a UK-based tool and cannot be used to assess bioenergy options outside the UK or other internationally sourced feedstocks (Forest Research, 2015).
- The results of BEAT2 tool are not transferable to case studies in other countries except the UK, since all the tool parameters were calculated for conditions within the UK.
- It provides the user with an indication of the likely impacts and benefits of different UK biomass options in specific situations, but it does not replace the need for a full impact assessment of individual plants (Biomass Energy Centre, 2015).
- BEAT does not include details on Land Use Control.
- The results from this tool do not replace a full impact assessment and should be used as evidence to start an informed discussion, and give only indicative results (Forest Research, 2015).

2.15 RSB Tool

2.15.1 Overview

Table 17 Round Table of Sustainable Biofuels (RSB Tool)

General characteristics of RSB Tool	
Tool name	Round Table of Sustainable Biofuels RSB Tool
Developer name	The software is developed by the RSB in collaboration with the Swiss Federal Institute for Materials Testing (former EMPA), Quantis and HTW Berlin.
General boundaries	Land-to-tank (Wheat Yield, Diesel Consumed, Fertiliser N_2O total figure, Fertiliser manufacture, N_2O emissions from residues ploughed in, Manure N_2O direct and indirect, Seeds, Pesticides, Manure delivery, Transport, Land use change, Straw Yield, Buildings)
Language of interface	English
Access/Installation Requirements	The RSB Tool is a freely available online tool. The user needs to create a new account first and provide a valid email address. http://buiprojekte.f2.htw-berlin.de:1339/ welcome

The RSB GHG Calculator is a lifecycle GHG calculator for biofuel production chain. The main objective for the development of this tool was to help small biofuel producers to comply with certain GHG emission criteria. Emissions shall be estimated via a consistent approach to lifecycle assessment, with system boundaries from land to tank, including carbon embedded in the fuel but excluding vehicle technology.

The RSB calculates GHG emissions in individual stages of the biofuel supply chain (Whittaker et al., 2013) according to the following methodologies (RSB, 2013):

(i) RSB GHG Calculation Methodology RSB-STD-01-003-01,

(ii) European Union (EU) RED Methodology and

(iii) the Swiss Methodology (MinOEV).

2.15.2 Methods / Technical characteristics

The sector-specific RSB Tool is modular. In other words, each step of the biofuel production process (feedstock production, transport, feedstock processing etc) is assessed as a separate module. Users can select their “scope of operation”, which refers to the lifecycle stage of the biofuel production that suits the specific operator. The final module “final transport or blending” is the only part of the tool that shows the emissions of the biofuel in gCO_2/MJ-fuel, as well as the results compared to the fossil fuel baseline. Each one of the rest of the modules show emissions in gCO_2/kg of the final product. In this framework, the result of every previous module is imported into the next module (RSB, 2013).

The calculations of background data (carbon intensity of fertilizer production processes etc) rely on data retrieved from the Ecoinvent database following the RSB methodology. The

GHGs included in the calculation and their associated GWPs are based on the ReCiPe method. ReCiPe metric includes more chemicals than IPCC (2007), but the latter includes 10 chemicals that are not included in ReCiPe (RSB, 2011). The RSB calculations are based the IPCC (Tier 2) when following the RED methodology (Whittaker et al., 2013).

2.15.3 *Case studies*

Some of the case studies that the RSB developers have conducted included projects about smallholder production operations. An indicative list of case studies includes the cassava in Cambodia, jatropha curcas in Indonesia, palm oil in Malaysia, coconut sap in the Philippines, soya and corn in South Africa, and sugarcane molasses in Thailand (RSB, 2015).

2.15.4 *Basic advantages / disadvantages*

Advantages

- The RSB tool has been specifically deployed in order to help biofuel producers calculate their GHG balance in compliance to RED guidelines.
- Although the RSB tool is not an excel-based tool, it provides a highly transparent manual.
- It is one of the most comprehensive tools, since has been designed depending on IPCC Tier 3 methodology.
- A detailed calculation widget is included for tillage, inputs and residue management (Whittaker et al., 2013).
- RSB tool includes the calculation of N_2O emissions due to manure application, even though most of the tools do not incorporate it (Whittaker et al., 2013).

Disadvantages

- The feature regarding the calculation of land use changes has a rather less user-friendly interface (Whittaker et al., 2013).
- Although the RED guidelines underlie the RSB calculator, a recently published comparative analysis of similar tools revealed the production of different results (Hennecke et al., 2012; Whittaker et al., 2013). The differences regarding the different estimations for land use change, and in particular for conversion of forestland, are based on the different emission factors used for fertilizer manufacture and N_2O emissions from soil (Hennecke et al., 2012).

2.16 HGCA Biofuel carbon footprinting decision support tool

2.16.1 *Overview*

Table 18 HGCA Biofuel carbon footprinting decision support tool

General characteristics of HGCA Biofuel carbon footprinting decision support tool	
Tool name	Home Grown Cereals Authority HGCA Biofuel GHG Calculator
Developer name	Developed by Imperial College, UK (Biomass Energy Group), commissioned

	by Home Grown Cereals Authority (the cereals and oilseeds division of the Agricultural and Horticulture Development Board in the UK)
General boundaries	Production and supply of biofuels
Language of interface	English
Access/Installation Requirements	The calculator is available upon request.

The main objective of the HGCA Biofuel carbon footprinting decision support tool is to increase environmental awareness regarding the emissions hotspots in the biofuel production process (HGCA and AHDB, 2012). In this context, farmers and biofuel suppliers can understand how management practices result in the production of GHG emissions. In specific, this tool accounts the GHG emissions throughout the life cycle of UK bioethanol and biodiedel production lines (Denef et al., 2012).

2.16.2 *Methods / Technical characteristics*

The sector-specific tool HGCA calculates the carbon footprint of a particular crop separately, or provides comparative analyses of different scenarios for the identification of areas where with the implementation of the appropriate measures efficiency gains can be made. It has to be noted that if a crop is inorganic, the carbon footprint calculator focuses on the annual crop inputs and yields. On the other hand, if there is an organic crop, such as cereal and oilseed systems, the tool accounts the carbon footprint over four (4) to six (6) years (HGCA and AHDB, 2012).

The methodology used for the calculation of the emissions in the biofuel production supply chain is a combination of several sources. In specific, the emission factors used per source category and GHG credits have been retrieved from the Low Carbon Vehicle Partnership study (LCVP, 2004). The LCVP GHG emission factors used for the calculation of the embedded emissions in fertilizers, pesticides and seeds are part of the studies of Elsayed et al. (2003) and Mortimer et al. (2004). As far as the N_2O emissions from fertilizers and the rest of N additions, a default emission factor is used depending on the amount of N applied. Finally, defra GHG reporting guidelines (defra, 2005) underlie the default emission factors used for calculating the emissions from the transportation (by rail, sea and air) (Denef et al., 2012).

The calculator is in the form of an MS Excel spreadsheet. The input data required are either actual figures from farm records for each crop or default values based on industry averages. Therefore, extended data input is required based on the factors that affect the carbon footprint of a crop (e.g. crop type and whether winter -or spring-planted, percentage of the crop grown on each of light, medium and heavy soils etc) (HGCA and AHDB, 2012).

Ultimately, it is mentioned that the final emissions in HGCA tool are expressed in $kgCO_{2e}$, in compliance with the suggestions of the industry for focusing on the carbon footprint per tonne of crop produced (rather than per hectare emissions). The main advantage of this approach is the compliance with the main objectives of the HGCA tool (i.e. increase environmental awareness and help stakeholders assess the impacts of different management decisions on the size of the carbon footprint of their crop) (HGCA and AHDB, 2012).

2.16.3 *Case studies*

The users targeted include bioethanol and biodiesel farmers, producers, suppliers, investors, NGOs, academics and policy makers (Denef et al., 2012). Therefore, the tool has been applied so far in case studies of winter wheat, malting barley and oilseed rape.

2.16.4 *Basic advantages / disadvantages*

Advantages

- User-friendly interface accompanied by support and guidance material.
- The sector-specific tool HGCA offers a straightforward and transparent way to calculate the carbon footprint of a particular crop (HGCA and AHDB, 2012).
- The calculator can be used for wheat to ethanol, oilseed rape to biodiesel and, provisionally, for straw to ethanol (HGCA and AHDB, 2012).
- The development of the HGCA calculator contributed for the deployment of biofuel and bioenergy calculators for the RFA,DfT and the Department of Energy and Climate Change (HGCA and AHDB, 2012).
- It is a tool that can focus either on inorganic systems (by calculating the carbon footprint on annual basis) or organic systems (by accounting the carbon footprint over the fertility-building and fertility-using phase) (HGCA and AHDB, 2012).
- HGCA carbon footprinting decision support tool is one of the prime examples, where the methodology built derives from several sources in response to the sector that the tool calculates the emissions for.
- The final emissions in HGCA tool are expressed in $kgCO_{2e}$, in compliance with the suggestions of the industry for focusing on the carbon footprint per tonne of crop produced (HGCA and AHDB, 2012).

Disadvantages

- Extensive information input is required, since data is needed for each crop separately (HGCA and AHDB, 2012).
- HGCA tool does not include details regarding land use changes (Whittaker et al., 2013).
- Since the HGCA tool does not comply with the RED guidelines, as it was developed before the RED establishment (Whittaker et al., 2013).

2.17 SENSE tool

2.17.1 Overview

Table 19 SENSE tool

General characteristics of SENSE tool	
Tool name	SENSE tool
Developer name	SENSE consortium is formed by a multidisciplinary team involving 23 partners from 13 countries made up by a combination of complementary profiles: research organisations (AZTI, SIK, UoI, AAU, CITY and DTU), food and drink SMEs (ZUVAMESA, TUNAY GIDA, PROVAC, CALION, FJARDALAX), IT developers (INGENET), environmental and LCA experts (ESU, EFLA and BIOZOON), SMEs for dissemination and communication and European food Associations (TRITECC, BA, CI, SGF, EAS, CLITRAVI) and SMEs for management (ZABALA).
General boundaries	Food chain and supply chain
Language of interface	English
Access/Installation Requirements	Regionalised LCA method Download or accessible via internet.

SENSE tool provides an evaluation system for the environmental impact assessment of food and drink products considering environmental and socio-economic aspects. The web-based calculator has been tested in juice, meat & dairy and aquaculture chains; however due to its modular construction, it is applicable in any food product (Ramos et al., 2014).

2.17.2 Methods / Technical characteristics

The methodology used in the SENSE tool is a combination of environmental impact assessment indicators applied in three food chains (dairy/beef, orange juice and salmon aquaculture). The Life Cycle Impact Assessment (LCIA) is the dominant method followed in most impact categories according to the International Reference Life Cycle Data System (ILCD) handbook (JRC, 2012). A full list of the life cycle assessment methodologies used per impact category is presented in Table 20.

The methodology used in SENSE tool comprises the exact same set of impact assessment methods as European Commission on the Product Environmental Footprint proposed later (EC, 2013). The same methods were also used in the ENVIFOOD protocol except for the indicators for water depletion (ENVIFOOD, 2012; SENSE, 2013; Ramos et al., 2014).

Table 20 Life cycle impact assessment methodologies used in the SENSE-tool

Impact category	Unit	Selected LCIA method	Reference
Climate change	Kg CO_2-eq	Bern Model - IPCC	Solomon 2007
Eutrophication terrestrial	Molc N-eq	Accumulated Exceedance	Posch et al., 2008
Eutrophication freshwater	Kg P-eq	EUTREND Model	Goedkoop et al., 2009
Eutrophication, Marine	kg N-eq	EUTREND Model	Goedkoop et al., 2009
Acidification	molc H+-eq	Accumulated Exceedance	Posch et al., 2008
Human toxicity	CTUh	USEtox Model	Rosenbaum et al., 2008
Ecotoxicity	CTUe	USEtox Model	Rosenbaum et al., 2008
Land use	kg C/m2/a	Soil organic matter model	Milà i Canals 2007
Abiotic resource depletion	kg Sb eq	CML 2002	Guinée et al., 2002
Water depletion	m3 H2O eq	Ecological scarcity model	Frischknecht et al., 2009

Source: Ramos et al., 2014

The user can either install the tool or operate it via internet. The tool has been developed using Visual Basic.Net, on Visual Studio 2010, and the embedded database engine is SQL Server 2008 R2. Furthermore, Photoshop CS 6 y Gimp 2.8 has been used for the interface imaging.

Input data can either be imported by the user or by fulfilling specific questionnaires to the main chain suppliers. In the second case, users are able to see the information fulfilled by the supplier only if suppliers provide authorization for this action (Ramos et al., 2014).

2.17.3 *Case studies*

The main objective of the tool is to help non-LCA expert industrial actors. In this framework, the SENSE tool has been used in the following cases:

- Calion Prod SrL, Dairy farm cooperative, Romania
- Aquaculture production, Fjaradalax, Iceland
- SSC PROVAC IMPEX SRL, Meat and milk production, Romania
- TUNAY GIDA, Fruit Processing Industry, Turkey
- ZUMAVESA, Fruit Processing Industry, Spain
- Icelandic aquaculture
- SC SORTIMEX PROD SERVCOM SRL, farm

- SC BASTO Import Export SRL
- INDULLEIDA, Spain

2.17.4 *Basic advantages / disadvantages*

Advantages

- Friendly interface.
- The web-based SENSE tool is modular allowing its application in any food product.
- The tool is accessible via internet or can be downloaded.
- In order to facilitate data gathering, the tool can distribute online questionnaires to the main suppliers of the chain (Ramos et al., 2013).

Disadvantages

- The tool has not been fully developed yet.

3 EVALUATION OF CARBON TOOLS

The carbon calculators previously described can be roughly categorized in three main sectors, namely food sector, arable crops and food & supply chain. Therefore, an evaluation of these tools could not be based on a comparative analysis. In this framework, certain common characteristics will be highlighted according to the general principles of the GHG Protocol Corporate Standard: relevance[2], completeness, consistency[3], transparency and accuracy[4] (Daviet, 2006). Furthermore, some additional features will be discussed as "lessons learned" for the development of the Foodprint calculator.

Transparency, consistency and accuracy:

Transparency means that the data sources, assumptions and methodologies used for an inventory should be clearly explained, in order to facilitate the replication and assessment of the inventory by users of the reported information (UNECE Reporting Guidelines).

Some tools provide details of the calculations, whereas some others display only the inputs and outputs (Carvalho et al., 2012). Tools that provide transparency allow the users to have access to the calculation methodologies. Therefore, tools, such as Cool Farm Tool, BEAT2 and Biograce are prominent in this category. The main reasons are the offer of access to the original excel-spreadsheets of calculations, or the provision of the emission sources. In addition, some tools provide information whether they calculate N_2O emissions, or if they state GWPs. The tools that cannot be characterized as transparent do not provide sufficient information regarding the emissions sources or provide details on the sources of emission factors.

Completeness:

Comprehensiveness refers to the inclusion of at least all sources and pollutants for which methodologies are provided in the tool inventory (Daviet, 2006). Therefore, certain characteristics -such as the enclosure of the emissions (e.g. direct N2O emissions) from fertilizers, the differences in N fertilizer types, N_2O emissions from crop residue incorporation etc- make the difference amongst the various tools. Cool Farm, RSB and Biograce tools are considered to be the most comprehensive, since they include land use changes and some of them have adopted Tier 3 IPCC methodology. In addition, both Cool Farm and RSB account emissions for land use changes in tillage, inputs and residue management. On the contrary, tools, such as CCalc and Muntons do not include N_2O

[2] "Relevance" stands for the appropriate system boundaries. The system boundaries of the Foodprint tool have already been set as cradle-to-shelf.

[3] *Consistency means that an annual inventory should be internally consistent for all reported years in all its elements across sectors, categories and pollutants* (UNECE Reporting Guidelines). Therefore, it is beyond the scope of this deliverable.

[4] *Accuracy means that emission estimates should be accurate in the sense that they are systematically neither over nor under true emissions, as far as can be judged, and that uncertainties are reduced as far as practicable* (UNECE Reporting Guidelines). BEAT2 tool includes some aspects of uncertainty (Whittaker et al., 2013). Therefore, it is an element that the Foodprint calculator should include.

emissions from soil and along with HGCA and BEAT that do not provide details about land use changes.

Lessons learned (additional principles):

Access: Two (2) out of the 15 tools assessed require a paid license. Even if the services provided are not equal to the free-license carbon calculators, the first limit their possible applications due to the subscription costs (Kim et al., 2008). There are also tools that provide both a paid license and free-of-charge versions (e.g. Cool Farm Tool v1.1).

User friendliness: In terms of user friendliness, the tools were rated according to recommendations by users, as well as scientific reviews. Ten (10) from the 15 tools described have a positive comment regarding the ease of use of their interface in the literature reviewed. Tools with the most positive comments regarding their access of use and the provision of support and guidance material were CCalc, Biograce and CFF, followed by HGCA and CoolFarm tool. Developers have emphasized on the design of their tools interface, however the tools that stood out were characterized by the fact that they could be used by everyone. The rest of the tools were lacking in instructions or required a password or installation (Whittaker et al., 2013).

Informative: Tools that are informative provide a clear breakdown of emissions, as well as results in various formats (Whittaker et al., 2013). Cool Farm Tool is one of the prime examples, followed by CFF, Biograce, Calm and BEAT.

Double counting: High aggregation of data can lead to double counting of the sectors' emissions (Amani and Schiefer, 2011). Therefore, the input data categories should be well organised (Amani and Schiefer, 2011; Scholz et al., 2008; Kim et al., 2011). In addition, the tool should follow the methodology used for the preparation of the national inventory for the same reason (CLA CALM calculator, 2015; RCGP, 2011).

From the abovementioned, the main characteristics that considered as advantages and should characterize Foodprint tool are:

- ✓ Cradle-to- shelf methodology for estimating GHG emissions
- ✓ Friendly interface.
- ✓ Modular methodology allowing its implementation in any food product.
- ✓ Not necessary to install the program, making its use even simpler 9 Excel-based calculations)
- ✓ Possibility for system expansion option or to introduce manually the percentage of the economic allocation of different incoming materials, such as packaging or main ingredients.

- ✓ Possibility to send the questionnaires to the main suppliers of the chain, facilitating data gathering.
- ✓ Uncertainty analyses

4 Decision Support Tools/Management Systems

4.1 Introduction

According to Schmidt (2009), an LCA or its part carbon footprint can only support decision making at the organizational scale if the analysis is conducted accurately and is comparable to the real production conditions. Currently, companies still have problems in calculating carbon footprints, in particular SMEs. In order to reduce the calculation problem, Larsen et al. (2009) suggest that companies should look at energy sources and potential material substitution (Stechemesser and Guenther, 2012).

In this framework, there are several decision support tools that sustainable infrastructures (e.g. agriculture and food industry) are assessed. These tools do not focus on just one sustainable sector but examine all three sectors of sustainable development (i.e. economic, environmental and social). Hence, it becomes evident that these tools, also called multi criteria analysis (MCA) tools, evaluate multiple sustainability criteria, such as the production of healthy food, protection of natural resources and landscape conservation among others. A list of the examined MCA tools for this deliverable is showed in Table 21. All of them have been developed for sustainable crops and/or farms, since -after conducting an extensive literature review- no MCA tools have been found (yet) for the food processing sector.

Table 21 List of multi criteria analysis tools (MCA)[5]

Name
BRM (Balancing and Ranking Method)
MEACROS, Multi-criteria Evaluation of Alternative CROpping Systems
MODAM, Multi-Objective Decision support tool for Agro-ecosystem Management
Pacini et al. (no name was proposed by authors to designate this method)
ROTAT + Farm Images, Images, Interactive Multi-goal Agro-ecological Generation and Evaluation of Systems
MASC, Multi-attribute Assessment of the Sustainability of Cropping systems
ROTOR, ROTations in ORganic farming systems
SAFA: The Sustainability Assessment of Food and Agriculture systems
FarmGAS
DNDC Tool DeNitrification-DeComposition

[5] Source: Based on Carof et al., 2013

4.2 BRM: Balancing and Ranking Method

4.2.1 Overview

BRM offers a new method for multi-criteria assessment and ranking of options, without the shortages of other methods (e.g. subjective evaluation of criteria weights etc) (Strassert and Prato, 2002). In specific, BRM is a ‘‘three-step procedure in order to provide an overall complete final order of options’’(such as cropping/farming systems). The proposed method consists of a family of criteria (i.e. name, description, scale, and indicator of any defined criterion) (Strassert and Prato, 2002).

4.2.2 Methods

Criteria scores are assembled in a data table that is used to produce an outranking matrix. Then, triangulation of the outranking matrix is performed to obtain an implicit provisional ordering of options. Finally, the balancing principle is applied to the provisional ordering of options: decision-makers balance the advantages and disadvantages of any pair of options with the pair-wise comparisons of options until a complete ordering of options is obtained.

4.2.3 Variables

The variables (or criteria) are the income in terms of economic criteria, soil erosion, nutrient and pesticide emissions in terms of environmental criteria and uncertainties in crop cultivation in terms of social criteria.

4.2.4 Evaluation

No cost of labour and subsidies are included in the economic criteria on this decision tool. Moreover, few input-related criteria are subject to optimization. Whatsoever, this method is a generic approach of multi-criteria evaluation assessments that it is not restricted to agriculture.

4.3 MEACROS: Multi-criteria Evaluation of Alternative CROpping Systems

4.3.1 Overview

MEACROS is a multi-criteria evaluation tool to compare and select alternative farming systems. This method assesses and ranks agricultural systems depending on agronomic, economic and environmental criteria, as well as on weighted criteria that are introduced by users (e.g. farmers) (Mazzetto and Bonera, 2003).

4.3.2 Methods

MEACROS is based on concordance analysis derived from the ELECTRE method (Mazzetto and Bonera, 2003; Nijkamp, 1977). The first stage of the software constructs an ‘‘impact matrix’’ that indicates the performance of each alternative farming system based on each of criteria chosen. The tables incorporated have rows that include the alternative farming systems, and columns that contain the evaluation criteria. The entries are the impact of each farming system based on a given criterion. The second stage bears a ‘‘priority matrix’’ that highlights the relative importance of the criteria selected. The outputs of the method are ranked farming systems.

4.3.3 *Variables*

This tool covers income, employment/labour and subsidies for economic variables, land and pesticide use and nutrient emission for environmental criteria and uncertainties in crop cultivation and human welfare for social criteria.

4.3.4 *Evaluation*

MEACROS tool is based on an outranking method allowing ranking of options. As it is a highly interactive tool of mathematical complexity, decision-makers that use MEACROS evaluate the importance of each criterion by attributing attribute weights, and hence a presentation of the users’ choices for each set of criteria. Another feature of this tool is the provision not only of a set of proposed criteria but also of new input by the users. Finally, it is noted that a sensitivity analysis of the outputs is also provided.

4.4 MODAM: Multi-Objective Decision support tool for Agroecosystem Management

4.4.1 *Overview*

MODAM is a static bio-economic modelling system that conducts an economic and ecological assessments of selected production methods at specific location and place, and sustainable land-use options. Along with these socio-economic conditions, the method assesses farmers’ decisions and proposes financial measures for the optimization of the agricultural land use at a farm or the surroundings (Zander and Kächele, 1999).
The model has been developed from the collaboration of three research projects, namely Schorfheide-Chorin project, Nationalpark Unteres Odertal project and a research program regarding the large scale transformation of land use to ecological farming.

4.4.2 *Methods*

MODAM is based on a linear programming tool for the optimization of land use alternatives on a purely economic basis. More specifically, this tool maximises a linear objective function of farm gross margin considering technical and environmental constraints. Parameters, such as year-to-year weather variability, farmers’ behavior on other farmers or the market are not taken under consideration in this tool.

The theoretical background of the tool lies on a multiple goal linear programming approach, consisting from five level of hierarchically-linked modules. In the first level, the technical coefficients are imported followed by the economic factors. The third stage incorporates the ecological evaluation, and the fourth generates the linear programming model. Finally, the fifth set of modules incorporates the widget for solving the equation system and importing the outputs to the Geographical Information System.

4.4.3 *Variables*

This MCA tool is based on the development of scenarios regarding price and policy-regulation for assessing the various impacts on farmers' decisions, ecological and economic parameters. MODAM requires expert knowledge for the description of the farm capacities and the associated site-specific farming activities. More specifically, the variables included are the income, employment/labour and subsidies and costs for economic variables, soil erosion, fertilizer use, land use, use of non-renewable resources and nutrient emissions for environmental criteria and uncertainties in crop cultivation and human welfare for social variables.

4.4.4 *Evaluation*

This tool considers many environmental criteria under the spectrum of the linear optimisation. Tools, such as MODAM, that are based on linear-programming models are based on the construction of mathematical equations out of decision problems. It is suggested that the adoption of this approach is unsuitable for problems of high complexity, such as social issues (Sadok et al., 2008). However, this does not apply to the case of MODAM, since it is a model that has been developed to assess the impacts of new economic and environmental management schemes on farmers' behavior.

In addition, MODAM is a tool that can easily enclose additional economic and ecological modules of new scientific knowledge, hence a larger number and more up-to-date scenarios can be evaluated.

4.5 *Pacini et al.*

4.5.1 *Overview*

The proposed methodology and field scale ecological–economic linear-programming model evaluate environmental and economic aspects of alternative management choices in compliance with multi-objective policy-making on the farm level (Pacini et al., 2004). The main scope of the tool is to increase the gross margin of the targeted farm/field activities by simulating farmers' management choices. Input data for the construction of the tool have been retrieved from an organic dairy farm of 241 head of livestock, located in the Mugello area of Florence, Northern Tuscany.

4.5.2 *Methods*

The methodology developed is based on farm/field scale ecological and economic linear programming model. At the first level of the model, the activities under consideration are imported in the model and evaluated compared to the available data from a representative farm in the surroundings and the standard model-farm of the tool. In this modelling framework, ecological models (such as GLEAMS) are also used (Knisel, 1993). Secondly, the evaluation outputs are assessed based on technical-environmental coefficients of the linear programming model. The tool also considers constraints, such as machinery, manure and slurry requirements etc. Finally, the main outputs comprise land use for each crop rotation, revenues and costs, as well as results associated to the environmental indicators used.

4.5.3 *Variables*

As far as the economic indicators are concerned, the tool comprises the crop yield, milk yield per cow, gross margin, labour requirements and the amounts of manure and slurry supplied by the herd. In addition, includes the income, subsidies and costs for economic variables, as well as environmental variables, such as the soil erosion, fertilizer use, land and water use, gaseous emissions and air quality for environmental criteria.

4.5.4 *Evaluation*

Based on the abovementioned, this tool does not consider any social aspects of sustainable agriculture systems while it assesses many economic and environmental criteria. Therefore, the use of the linear programming model is sufficient for handling the scenarios developed.
In addition, a re-arranging of the model's spatial structure by embedding characteristics of pedo-climatic conditions (e.g. shares of crops, hilly/flat areas, irrigated/non-irrigated land and ground/surface water withdrawal etc) would elevate the model for addressing agri-environmental scheme changes.

4.6 ROTAT + Farm Images: ROTATion tool + Farm Interactive Multi goal Agro-ecological Generation and Evaluation of Systems

4.6.1 *Overview*

ROTAT generates with transparency all the feasible crop rotations adhering to a set of agronomic rules. This tool assesses a broad range of production activities at the field scale (crop rotations and crop-management systems) and then suggests a combination of the best production activities for achieving sustainable development. This software tool uses agronomic criteria, meaning a finite number of crop combinations from a default list in order to generate all possible rotations. The maximum number of all the possible crop combinations is limited by the user, eliminating the non meaningful by an agronomic point of view crop suggestions already in the early stages (Dogliotti et al., 2003).

4.6.2 *Methods*

This ROTAT approach comprises two main steps. The first step includes a set of alternative cropping systems generated and assessed based on various ecological models. In general, all crops that may be grown under particular production conditions, but not all of these are agronomically feasible. Therefore, in the second stage, the outputs of the allocated cropping systems are used as input data for the design of alternative farming systems using multiple-goal linear programming.

The tool has been implemented in case studies, such as 10 Dutch ecological pilot farms in Flevoland in the Netherlands (Vereijken, 1997) and vegetable farms in South Uruguay (Dogliotti et al., 2004, 2005).

4.6.3 *Variables*

The parameters for limiting the number of crop combinations can be adjusted by the user, and are grouped in three main categories, namely: (i) Timing constraints, (ii) Sequence and frequency constraints, and (iii) Farm-specific feasibility and applicability. The first set of filters comprise parameters, such as sowing and harvesting dates and/or minimum intercrop period. The second group includes restrictions on crop successions, maximum frequency of each crop in the rotation, and maximum frequency of groups of related crops and minimum period before repeating cultivation of a crop. As far as the third set of parameters is concerned, it encloses the maximum length of the rotation in years, maximum number of different crops per rotation, maximum number of main crops and maximum number of secondary crops per rotation. The outputs of the first allocation are quantified using process simulation models along with empirical data and expert knowledge.

4.6.4 *Evaluation*

ROTAT was developed to assess farming-system sustainability by involving farmers' management choices. The users can adjust any of the ROTAT parameters depending on the situation, by controlling the filters provided by the tool (e.g. time constrains, sequence and frequency constraints, as well as feasibility and applicability on the farm level). By that means, the choice of filters in the linear programming model is affected by the users. In this context, the main outputs include land use for each cropping system, soil erosion, soil organic matter, nitrogen surplus, and exposure of the environment to pesticides, and, in addition to the abovementioned, several results deriving from the economic evaluations, such as net margin, family income, capital requirement, but without considering subsidies.

4.7 MASC: Multi-attribute Assessment of the Sustainability of Cropping systemsOverview

4.7.1 *Overview*

MASC is a non-linear recursive process that conducts sustainability assessments for cropping systems based on qualitative economic, environmental and social criteria, as well as on ‘‘if-then’’ decision rules for criteria grouping. The assessment framework comprises three steps that has been developed within a decision support system (Sadok et al., 2009).

4.7.2 *Methods*

MASC is a multi-attribute decision model that offers users an easy definition of the weight of each criterion in the decision-making process. The three-step approach comprises (i) the generation of cropping tools that are imported in the decision model, (ii) that are represented as vectors of sustainability criteria and processed by MASC and finally (iii) the outputs for the selection for the alternative systems to be tested in field trials.

MASC has been implemented within a decision support system, namely DEXi that is based on DEX methodology. In this framework, the tool assesses cropping systems from 32 measureable basic criteria and 22 aggregate criteria, which are hierarchically organised. These terminal nodes of the hierarchy, actually, consist the model inputs. The second step that includes aggregate attributes constitute internal nodes framing the model hierarchy, and represent intermediate output of the assessment as a function of all attributes located below it (third step).

4.7.3 *Variables*

MASC tool comprises economic (e.g. income, employment and subsidies), environmental (such as, soil erosion, pesticide use, use of non-renewable resources, nutrient, gaseous and pesticide emissions, soil quality and agricultural biodiversity and water use) and social criteria (for example, uncertainties in crop cultivation, human welfare and input self-sufficiency).

It has to be noted that social criteria, which are rarely evaluated in this type of tools, are generally summarized into three groups: (i) input self-sufficiency, (ii) human welfare and (iii)risk and uncertainties in crop cultivation. MASC tool is an exception to this empirical rule, since it includes criteria, such as contribution to local employment or physical constraints.

4.7.4 *Evaluation*

MASC, as a multi-attribute decision model that can help decision-makers distinguish assessment tools from one another by using simple categories. It allows its users to modify weights and threshold values during the evaluation process using a linear regression method. Nevertheless, despite the comparison of the alternatives, MASC also provides ranking of them in an absolute way.

It has to be noted that MASC is a method devoted to cropping systems but not fully adapted to the assessment of the organic systems.

4.8 ROTOR: ROTations in ORganic farming systems

4.8.1 Overview

ROTOR is a static rule-based model that assesses sustainable crop rotations and management systems for specific locations of northeastern Germany, cultivated under organic farming conditions (Bachinger and Zander, 2007).

4.8.2 Methods

ROTOR consists of two main stages. In the first stage, the tool uses a relational database to select a set of annual crop production activities for all crops feasible for a specific site considering soil quality and rainfall. The database includes all relevant crops recorded that are defined as sets of individual field operations, from stubble tillage to harvest. These activities are evaluated using rule-based assessment modules. In the second stage, all possible sequences of crop production activities are linked to three (3) to eight (8) preliminary crop rotations, and then agronomically sustainable crop rotations are selected and ranked by performance.

4.8.3 Variables

ROTOR considers various criteria within the two-step evalutions conducted. The crop production activities are assessed based on income, yields and employment/labour for economic criteria, fertilizer and nutrient and weed infestation risks. The agronomically sustainable crop rotations are chosen depending on environmental criteria and uncertainties, such as thresholds for N balance, phytosanitary, weed infestation risks and chronological constraints.

4.8.4 Evaluation

ROTOR is a tool restricted to organic cropping systems, but one of the least comprehensive methods. It comprises few criteria for the input evaluation, such as fertilizer and water while no subsidies and yield are included in the economic criteria. However, it describes detailed costing for the income and the employment/labour criteria. In general, this tool provides generation of alternatives using algorithms and static equations, but the whole evaluation is restricted to the alternatives provided.

4.9 SAFA: The Sustainability Assessment of Food and Agriculture systems

4.9.1 Overview

SAFA was deployed by FAO for assessing the impact of food and agriculture operations. The SAFA concept is that food and agriculture systems are characterized by all four dimensions of sustainability: good governance, environmental integrity, economic resilience and social well-being. In other words, SAFA is a holistic assessment framework for the sustainability of food and agriculture value chains. Its main objective is to support the implementation of effective sustainability management and communication in the enterprises of the food and agriculture sector (SAFA, 2014).

4.9.2 *Methods*

SAFA Tool contains four stages, namely (i) mapping, (ii) contextualization, (iii) indicators and (iv) Reporting. In the first stage, mapping the supply chain highlights what is being measured, sets the boundaries and shows what interactions take place in the production line under consideration. The stage of contextualization comprises a broad range of information regarding the context of the entity that has to be (e.g. resource availability, labour trends, legal framework etc). In the next step, an input screen for collecting data is provided from the indicator question answers, defining the accuracy score and rating the indicator performance. Finally, during the stage of reporting, the outputs create transparency.

It has to be noted that the SAFA Guidelines are based on the Bellagio Stamp, ISO norms for LCA, ISEAL Code of Good Practice, ISEAL Credibility Principles, Reference Tools of the GSCP, and the GRI Sustainability Reporting Guidelines.

4.9.3 *Variables*

The indicators used for the evaluation of sustainability schemes are the SAFA Indicators that are provided in the Guidelines’ complement. Key performance (default) indicators for 21 themes and 58 sub-themes are provided. Core performance indicators aim at providing standardized metrics to guide assessments on sustainability. In total, there are 118 SAFA indicators that have been developed through practitioner and expert analysis of what constitutes the most critical individual components of each sub-theme. The holistic framework represented by the themes encompasses all aspects of sustainable cropping, livestock husbandry, fisheries, aquaculture and forestry production, postharvest, processing, distribution and marketing.

4.9.4 *Evaluation*

SAFA provides an international reference tool for assessing the sustainability performance of food and agriculture enterprises. The main advantage of the SAFA framework is the provision of a common language for sustainability that can be adjusted to different users' needs. During the first stage of the method, sustainability polygons, like the one in the following figure, are created depicting the current and future situation without the programme and for each alternative intervention. Comparing the different polygons, the user can select the most sustainable alternative in each area of work, along with the provision of technical support to decision-making by SAFA.

Figure 3: Example of a SAFA sustainability polygon (SAFA, 2014)

4.10 FarmGAS Tool

4.10.1 Overview

The FarmGAS tool is a web-based primarily a decision support tool for the examination of the GHG emissions and financial impacts that different greenhouse mitigation choises may have on the farm business profitability (AFI, 2013). The tool is consisted by two “sub-tools”, namely the FarmGAS Calculator Scenario Tool and the FarmGAS Financial Tool. The tool, developed by the Australian Farm Insitute, is based on GHG emissions calculator and has focuses on business managers (Denef et al., 2012). It has to be noted that the carbon farming project approvals are administered by the Australian Government’s Clean Energy Regulator.

The FarmGas Calculator is an online tool that estimates GHG emissions output for farm-based scenarios. The FarmGas Calculator provides estimates of GHG emissions based on the accounting method used by the Australian Government Department of the Environment’s National Greenhouse Gas Inventory (NGGI) reporting requirements (AFI, 2014). The main objective in developing a carbon farming decision support tools was the increase of the farmers’ environmental awareness. However, the challenge remains to develop an approved carbon farming project methodology for an emissions reduction activity that is applicable for the sheep, beef cattle and grains farm businesses (AFI, 2014a).

The FarmGAS Financial Tool allows the farm enterprise to compare the costs for various on-farm activities, and to determine the most cost-efficient scenario for investment. The scenarios include a broad range of farming projects and require inputs related to emissions, such as fertilizer use. In general, the FarmGAS Financial Tool assesses the financials of the users' projects against the amount of emission reduction or sequestration each scenario can achieve.

4.10.2 *Methods*

The FarmGAS Calculator Scenario Tool estimates GHG emissions from agricultural enterprises and farms. This tool enables the user to investigate GHG abatement options through modifications of emission calculators and "what if" scenarios. The key features of the tool are the modifiable model farms and the financial tool attached to the calculator, as well as the range of enterprise types comprised, the tree lots, pastures and savanna, the multiple farms/scenarios and that the results can be printed and saved in a table structured format, i.e. Comma Separated Values files (CSV files). This is presented in a graphical way by means of what is known as a Marginal Abatement Cost Curve referred to as a Marginal Abatement Cost curve (MAC curve or MACC) (AFI, 2014c).

More specifically, the calculations in the FarmGAS Calculator Scenario Tool are based on the internationally accepted accounting method used by the Department of Environment to estimate Australia's emissions from the agricultural sector. The NGGI uses a range of production and emission factors combined with industry data for calculating emissions from the agricultural sector. Livestock numbers, crop and wool production are sourced from the Australian Bureau of Statistic census/survey data, ABARES and industry. Numbers of feedlot cattle are sourced from the Australian Lot Feeders Association and milk production statistics from Dairy Australia. The areas of savanna burnt are largely based on a time series of satellite images processed by WA Department of Land Information.

Additional information on animal liveweights, liveweight gains, pasture digestability, savanna fuel loads, combustion rates and other agricultural production factors are based on reviews of published data and expert assessments. As a result, it has to be noted that the FarmGAS Calculator Scenario Tool has been designed to replicate the national calculations but at the farm level. Emissions estimated from FarmGAS Calculator Scenario Tool are therefore, largely aligned to the National method of calculating emissions but are more specific at the farm level. The main differences between FarmGAS Scenario Tool and the established national method are shown in the following figure.

The FarmGAS Calculator Scenario Tool provides the User with an option to conduct financial modelling, that includes Net Present Value analysis of project comparisons from a separate decision making platform. Users of FarmGAS Calculator Scenario Tool that prefer not to conduct the advanced level of financial modelling can use the default options (gross margins and other financial summaries) available in the standard FarmGas Calculator Scenario Tool (AFI, 2014b). In line with the description of the FarmGAS Calculator Scenario Tool, the key features of the FarmGAS Financial Tool comprises a range of farm enterprise types (beef breeding, beef stores, beef feedlot, sheep production and dryland and/or irrigated crops), multiple farms/scenarios and results can be printed and saved to CSV files.

The FarmGas Tool has been used in farms covering sheep, beef and grains enterprises throughout eastern Australia. The competent body, i.e. the Australian Farm Institute, has also conducted several case study analyses in order to support key messages for the use of FarmGas Tool, as well as to provide step-by-step decision support tool for covering sheep, beef and grains enterprises. Some of the case study analyses that are available include farms with beef cattle, sheep, cropping (irrigated, dryland etc), pastures, piggery (AFI, 2013).

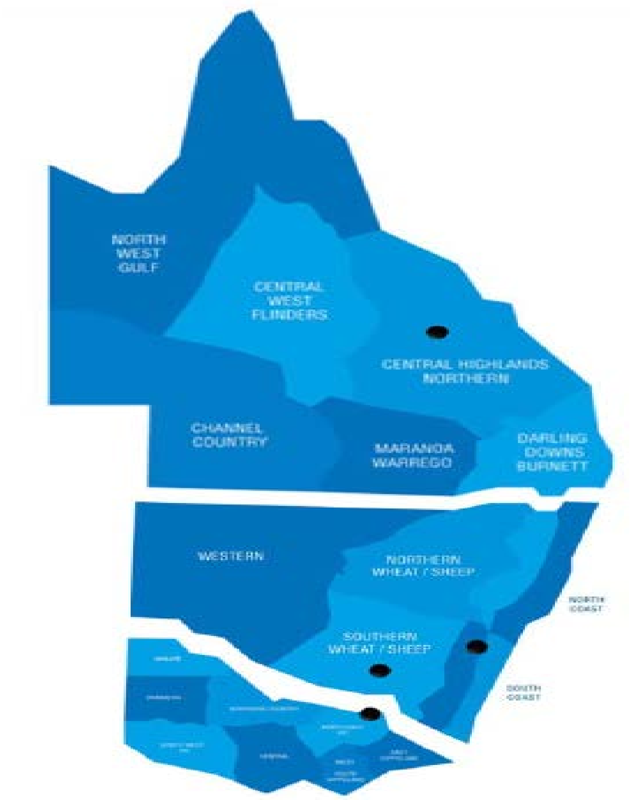

Figure 4: Farm business case study locations across eastern Australia (the black dots indicate farm business case study locations) (AFI, 2014)

4.10.3 *Variables*

FarmGAS uses the calculations and emission factors described in the Australian Methodology for the Estimation of GHG Emissions and Sinks 2006 for the sector of Agriculture (AGDCC, 2006). This methodology, used by the Department of Climate Change in determining Australia's National GHG Inventory (2008), comprises country-specific and IPCC methodologies, as well as emission factors (Denef et al., 2012). The underlying databases comprise sources, such as the Australian Bureau of Statistics, the Australian Lot Feeders Association, the Dairy Australia, the WA Department of Land Information as well as official published data (Denef et al., 2012). The practices covered comprise extensive cropping systems, extensive grazing systems, intensive livestock (but no dairy), horticulture and farm trees. The GHG covered in the FarmGAS Tool include CO_2, CH_4 and N_2O.

4.10.4 *Evaluation*

Pros

The FarmGAS Calculator Scenario Tool provides a Default and a Revised set of calculations. Most calculations are consistent with the NGGI, but because the model is constructed to enable farm-level enterprise activities, some calculations and production factors use farm values rather than National/State averages. Where possible, the Default calculations apply the NGGI values (production variables and emission factors). Unless amended by the User, the Revised calculations also apply the NGGI variables and factors in the same way as the Default.

The Revised option allows the User to change many of the Default values of production and emission factors, and in this respect may produce Greenhouse Gas estimates that are very different than those of the NGGI. However, the Revised option has considerable capacity to include NGGI-based factors that are not possible in the Default option (due to the farm-level design), and in many cases the revised factors can be made to mirror the NGGI. The purpose of the Revised option is to provide the User with information about how changes in farm activities and inputs will affect levels of Greenhouse Gas emissions, compared with the standard Default. Of course, different sets of Revised results, based on different sets of farm activities, can also be used to provide information about managing Greenhouse Gas emissions. It has to be noted that the areas where the FarmGAS Calculator Scenario Tool complies with the NGGI methodology are outlined in the User Guide of the tool.

Finally, the MACC used to present the costs and returns of the enterprise's projects in the FarmGAS Financial Tool allows the enterprise to quickly evaluate the best value project or activity for reducing emissions. The comparison allows the enterprise to identify those scenarios where conducting a more detailed analysis should be undertaken before committing to the project (AFI, 2014c).

Cons

FarmGAS Calculator Scenario Tool can only be used within the scope of the included enterprises. This means that enterprises such as rice and sugar cane are not included in FarmGAS Calculator Scenario Tool. Additionally, FarmGAS Calculator Scenario Tool does not calculate some soil-based emissions, such as agricultural liming and the application of organic fertilisers, nor carbon sequestration from activities which affect soil carbon, as the calculations and data input requirements are either too complex, or the emissions are not included in the NGGI for the Agricultural sector. For example, liming and organic fertilizer applications and soil carbon are included in the Land Use, Land Use Change and Forestry (LULUCF) sector. The sequestration of carbon in trees is also included in the LULUCF sector, however FarmGAS Calculator Scenario Tool provides estimates of potential tree carbon sequestration as a guide to the potential for offsetting the farm's total emissions (AFI, 2014b).

4.11 DNDC Tool DeNitrification-DeComposition

4.11.1 *Overview*

The DNDC-DeNitrification-DeComposition tool is a computer simulation model of carbon and nitrogen biogeochemistry in agro-ecosystems. The model can be used for predicting crop growth, soil temperature and moisture regimes, soil carbon dynamics, nitrogen leaching and emissions of trace gases including nitrous oxide (N_2o), nitric oxide (NO), dinitrogen (N_2), ammonia (NH_3), methane (CH_4) and carbon dioxide (CO_2) (The DNDC Model, 2015). The US-DNDC Model is a decision support system for quantifying impacts of management alternatives on greenhouse gas emissions from agro-ecosystems in the U.S. (The DNDC Model, 2015).

4.11.2 *Methods*

The Denitrification-Decomposition (DNDC) model is a process-oriented computer simulation model of carbon and nitrogen biogeochemistry in agroecosystems. DNDC model provides simulations to compute all GHG emissions (CO_2, N_2O and CH_4) for production, consumption and transport (Gilhespy et al., 2014). More specifically, DNDC integrates ecological drivers in three sub-models to generate their collective effects on soil temperature, moisture, pH, Eh and substrate concentrations. The links between these soil environmental variables to production and consumption rates of trace gases in DNDC are set up based on either the basic physical, chemical or biological laws or equations obtained from experiments under controlled conditions so that the effect of each soil variable can be distinguished (Denef et al., 2012).

More specifically, the model consists of two components. The first one, comprises the soil climate, crop growth and decomposition sub-models, and the second, contains the nitrification, denitrification and fermentation sub-models, predicting emissions of carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), nitric oxide (NO), nitrous oxide (N_2O) and dinitrogen (N_2) from the plant-soil systems. To parameterize each specific geochemical or biochemical reaction, classical laws of physics, chemistry and biology, as well as empirical equations generated from laboratory studies, have been incorporated in the model. The entire model forms a bridge between the C and N biogeochemical cycles and the primary ecological drivers (User's Guide for the DNDC Model, 2012).

The model has been widely applied to estimate N_2O emissions from agricultural fields and dairy farms, as well as CH_4 emissions from rice fields and soil organic carbon dynamics (Denef et al., 2012). Indicatevely, the tool has been used for:

- an annual crop simulation in a maize growth in Iowa USA, where the field experiment focused on crop development,
- a perennial crop simulation for a sugarcane growth in Hawaii USA,
- a long-term soil organic carbon simulation (150-year SOC dynamics) in a winter wheat field at Rothamsted UK,
- an estimation of N_2O fluxes from a crop field in Arrou, France,
- methane fluxes from a paddy rice field in Texas, USA (UNH, EOS, 2012).

4.11.3 *Variables*

The entire model contains four primary ecological drivers, namely climate, soil, vegetation and management practices. Therefore, a successful simulation shall obtain adequate and accurate input data about these four primary drivers. (UNH, EOS, 2012). More specifically, since plant growth plays an important role in regulating the soil C, N and water regimes, a sub-model was built in DNDC for its simulation. The crop parameters include maximum yield, biomass portioning, C/N ratio, season accumulative temperature, water demand and N fixation capacity. In regards to the crop growth simulation, the accumulative temperature, N uptake, and water stress at a daily time step are considered. All the crop parameters are accessible to users, thus modifications are allowed.

In DNDC, soil organic matter resides in four major pools: plant residue (i.e. litter), microbial biomass, humads (i.e. active humus), and passive humus. Several sub-pools are also provided, where the pool size, the specific decomposition rate, soil clay content, N availability, soil temperature, and soil moisture are considered.

4.11.4 *Evaluation*

During the last 20 years, DNDC has been modified and adapted by various research groups around the world to suit specific purposes and circumstances. In more recent years, DNDC has formed the basic structure of increasingly more complex modular-based models, such as Moblie-DNDC and Landscape-DNDC. A number of models that have been developed for different regions of the world is also available (e.g. NZ-DNDC, UK-DNDC, and specific crops, DNDC-Rice, DNDC-SCW etc). At the same time, many further improvements have been added to the DNDC model itself. In Li et al. (2006), further enhancements were introduced to improve the model capacity for simulating free NH_4^+ dynamics, nitrification, and NO_3^- leaching.

A function was also added to the DNDC model in order to improve estimates of soil evaporation under different levels of surface residue cover. Recent versions of DNDC share the same soil NH_3 algorithms as Manure-DNDC, described in detail by Li et al. (2012). DNDC has also been improved in simulations of crop growth, and alternative farming management practices such as the use of nitrification inhibitors, slow-release fertilizers, sprinkler and drip irrigation, plastic film mulching etc. to meet the demand for GHG mitigation studies. To this end, two basic hydrological features were added to DNDC to enhance its capacity for modelling surface runoff and soil erosion (Deng et al., 2011; Gilhespy et al., 2014).

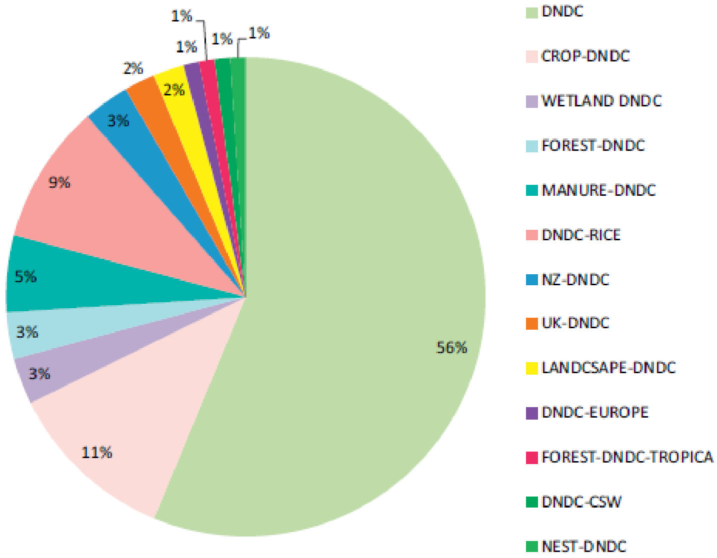

Figure 5: Percentage of survey respondents using each version of DNDC (Source: Gilhespy et al., 2014)

5 Evaluation of Decision Support Tools

The decision support tools evaluated in this deliverable do not focus on just one sustainable sector. In this context, a comparative analysis of these tools is not provided due to their fundamental differences. Instead a separate evaluation of each tool depending on the characteristics of each application field was chosen.

Based on the abovementioned, the main characteristics that considered as advantages and should characterize Foodprint tool are:

- ✓ Main criteria should be benefits and costs of the interventions, expected damage of the environment, etc.,
- ✓ Each subdivided into constituent criteria of lower hierarchy.
- ✓ Costs should be divided up in monetary and in-kind costs, benefits into economy, safety, and health, with a further subdivision of economy.
- ✓ The degree of the adverse effects will be measured in loss of water resources, coastal zones, land, biodiversity, etc.
- ✓ The stakeholder participation during this phase of the proposed activity is considered to be of paramount importance.
- ✓ The MCA tool should be able to produce scenarios for the reduction of the carbon footprint in a food industry while actions that will be evaluated and reports analyzing the effectiveness of each scenario will be produced.
- ✓ The predicting performance of the tool should be measured with the use of appropriate, measures of risk or uncertainty that will be included in the performance data.

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