A WORLD BANK STUDY

Carbon Footprints and Food Systems

DO CURRENT ACCOUNTING METHODOLOGIES DISADVANTAGE DEVELOPING COUNTRIES?

Paul Brenton, Gareth Edwards-Jones,
Michael Friis Jensen

THE WORLD BANK

WORLD BANK STUDY

Carbon Footprints and Food Systems

Do Current Accounting Methodologies Disadvantage Developing Countries?

Paul Brenton
Gareth Edwards-Jones
Michael Friis Jensen

THE WORLD BANK
Washington, D.C.

1818 H Street NW
Washington DC 20433
Telephone: 202-473-1000
Internet: www.worldbank.org

1 2 3 4 13 12 11 10

ISBN: 978-0-8213-8539-5
eISBN: 978-0-8213-8544-9
DOI: 10.1596/978-0-8213-8539-5

Library of Congress Cataloging-in-Publication Data

Carbon footprints and food systems : do current accounting methodologies disadvantage developing countries? / by Paul Brenton . . . [et al.].
p. cm.
Includes bibliographical references and index.
ISBN 978-0-8213-8539-5 (alk. paper)—ISBN 978-0-8213-8544-9 (electronic : alk. paper)
1. Greenhouse gases—Measurement. 2. Greenhouse gas mitigation. 3. Tropical crops—Environmental aspects. 4. Food industry and trade—Environmental aspects. I. Brenton, Paul.
TD885.5.G73C365 2010
363.738'746091724—dc22 2010032275

Contents

List of Tables

List of Figures

Acknowledgments

We would like to acknowledge and give thanks to all of the farm owners, agricultural managers, factory managers, and other industry individuals in Mauritius and Zambia who gave their time and information to help make this analysis possible. We are also very grateful to Jocelyn Kwok and Raïfa Bundhun for their logistical and institutional support in Mauritius, and the staff in the World Bank offices in Port Louis and Lusaka.

We wish to also extend our thanks to Simon Lumley, John Hall, and Graham Sinden, all of whom offered advice and technical input to the work.

The authors would like to acknowledge the generous financial support received from the governments of Norway, Sweden, and the United Kingdom through the Multi-donor Trust Fund for Trade and Development that made this publication possible.

Responsibility for all errors, omissions, and opinions rests solely with the authors. All findings, interpretations, and conclusions expressed in this paper are entirely those of the authors and do not necessarily represent the views of the World Bank, its Executive Directors, or the countries they represent.

About the Authors

The study was prepared by three main authors, Paul Brenton, Gareth Edwards-Jones, and Michael Friis Jensen, assisted by the three co-authors, Nicola Attarzadeh, Andrew Norton, and Katharina Plassmann.

Paul Brenton is a lead economist in the Africa Department (AFTPM) in the World Bank. Gareth Edwards-Jones is a professor in agriculture and land use studies at the School of Environment and Natural Resources, Bangor University, Wales. Michael Friis Jensen was formerly a senior economist in the International Trade Department (PRMTR) at the World Bank. He is currently Project Senior Researcher at the Danish Institute for International Studies.

Nicola Attarzadeh is a consultant with the environmental consultancy CarbonRoots. Andrew Norton is a consultant with the environmental consultancy Renuables, and Katharina Plassmann is a researcher based at the Institute of Agricultural Climate Research of the Federal Research Institute for Rural Areas, Forestry and Fisheries (vTI) in Germany.

Abbreviations

AEZ	agro-ecological zone
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
EF	emission factor
GHG	greenhouse gas
GWP	global warming potential
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardisation
LCA	life cycle assessment
LDC	less developed country
LUC	land use change
N_2O	nitrous oxide
OECD	Organisation for Economic Co-operation and Development
PAS 2050	Publicly Available Specification 2050 (carbon footprint standard)
UNFCCC	United Nations Framework Convention on Climate Change
WRI	World Resources Institute

Executive Summary

Background

Carbon accounting and labeling for products are new instruments of supply chain management that may affect developing-country export opportunities. These instruments are used to analyze and present information on greenhouse gas emissions of products in an attempt to identify major sources of emissions in supply chains. Once the emissions from different parts of a supply chain have been identified, it is hoped that actions can be taken to reduce emissions in a timely and cost-effective manner. Within the food sector there are typically four forms of action that can be taken:

- Voluntary responses by companies to the challenge of climate change. These may also bring commercial advantage through enhanced marketing and public relations.
- Action by governments to encourage companies to reduce their emissions. These may also help governments meet their international obligations for reductions in greenhouse gases (GHGs).
- Action by retailers to stock only products that meet a certain "standard" in terms of their carbon footprint.
- Action by retailers to place a label on products that informs consumers about the carbon footprint of that product, enabling consumers to make informed choices between products.

Designers of carbon accounting schemes have to respond to policy and corporate agendas to create new ways of responding to climate change challenges; however, they also have to be mindful of the very rudimentary nature of the knowledge that exists on actual greenhouse gas emissions emanating from the varied production systems around the globe. Knowledge about greenhouse gas emissions of is particularly lacking in the area of production and processing activities in developing countries.

Because of these knowledge gaps there is a risk that carbon accounting and labeling instruments will not properly represent the situation in developing countries. Carbon accounting and footprinting are helpful for understanding the impacts of an activity on climate change, but they are not necessarily good indicators of overall sustainability. This is important, because if consumers in developed economies respond to carbon labels by altering their purchasing patterns, which may include avoiding some products from developing countries, this may lead to unintended and undesirable outcomes in those developing countries.

The main objectives of this research are as follows:

- To summarize and compare different schemes that have been devised to identify the levels of greenhouse gas emissions associated with food products
- To determine the ease with which primary data and emission factors can be collected concerning food products from less developed countries
- To calculate the carbon footprints of chosen tropical commodities and assess the variation that arises when different guidelines are followed
- To assess the difficulties that less developed countries may have in meeting the demands posed by different footprinting schemes

- To provide recommendations for development-friendly carbon labeling and accounting based on the information collected

Methods

Current carbon footprinting methodologies were reviewed, and their similarities and differences in approach were noted. A carbon footprint was calculated for each of two products typical of the exports of developing countries. These were sugar from Zambia and Mauritius and pineapples from Mauritius. Primary data were collected in the field specifically for this project. Carbon footprints from the field to the port at the importing country were calculated using the PAS 2050 carbon footprinting method (BSI, 2008a). This method was chosen as the baseline for calculations here because it is currently the only method with detailed guidelines published. These case studies were then used to explore some of the methodological difficulties inherent in estimating carbon footprints for foods from less developed countries (LDCs). Finally, some recommendations on achieving development-friendly carbon footprinting methods are presented.

Results

Review of Carbon Footprinting Methodologies

At least 16 different methodologies for calculating the carbon footprint of a product have been developed since 2007 or are still under development. These tools for calculation and communication include nationally and internationally recognized standards, such as ISO, as well as instruments established by supermarkets. Countries in which standards are being developed include the United Kingdom, Germany, France, Switzerland, Sweden, New Zealand, the United States, Japan, the Republic of Korea, and Thailand. The footprinting methodologies vary tremendously in approach and methodology. Some of the methodologies are publicly available and provide users with detailed advice on how to undertake a carbon footprinting exercise (such as PAS 2050, developed by the Carbon Trust, United Kingdom), some have been developed but the detailed methodology is confidential, and the majority are still under development.

Data Quality and Availability

Many of the carbon footprinting methods require the use of generic data, such as emissions from energy generation, emissions from soils, and emissions from land use change and transport. The databases typically used in life cycle assessment hold some of these data, but they can be expensive and require technical knowledge to use. There are publicly accessible resources that present some of the data required to calculate the carbon footprints of agricultural products. However, most of the available data apply to industrialized countries in Europe, North America, and Australasia. Where data are available for LDCs, they tend not to be country specific and are normally relevant only to very large geographic regions. In addition, these data can be surrounded by considerable uncertainty.

Because of the nature of the available data, analysts are forced to use the best available data for a region without really knowing how valid these data are to the specific case being analyzed. Even if there are one or two scientific studies available for a certain country, it is unclear how widely applicable these data are, and whether or not they can adequately describe the situation across the whole country. The issue of the representativeness of available data is perhaps of more importance in relation to LDCs than it is for many European situations, as many developing countries are larger than most European countries and contain very varied ecosystems, microclimates, and agricultural practices. One way to approach the development of suitable emission factors and data for use in developing countries is to create data sets that are relevant across agro-environmental zones. This would enable some sharing of data between countries and would also allow natural variation within countries to be represented in a relatively simple and understandable form.

Calculating Carbon Footprints for Sugar and Pineapples

Carbon footprints were calculated for four products according to the methodology specified in PAS 2050: (1) sugar from Zambia, (2) sugar from Mauritius, (3) fresh pineapples and (4) pineapple jam from Mauritius. PAS 2050 requires that emissions from land use change be included in the footprint if the land used for production was cleared after 1990. This was the case in Zambia, and emissions from land use change had the greatest impact on the carbon footprint of sugar from Zambia. In Mauritius the agricultural fields had been cleared of native vegetation prior to 1990, and land use change emissions were not included in the carbon footprint; as a result the footprint was considerably lower than the one for Zambia (total kg CO_2e/t sugar at import port: Zambia 2.1, Mauritius 0.4).

The footprint of the sugar from Mauritius compares favorably with that for sugar produced in Europe from sugar beets, which has been estimated at 0.6 kg CO_2e/kg sugar up to the delivery of the product to food and drink manufacturers in the United Kingdom (www.britishsugar.co.uk) and 1.46 kg CO_2e/kg sugar in Germany (Stratmann et al., 2008).

The total carbon footprint for delivering fresh pineapples to Europe was 11 kg CO_2e/kg. Over 95 percent of this footprint is due the emissions from air freight. In contrast, pineapple jam had relatively low emissions from transport as it was shipped to Europe (total footprint of 1.3 kg CO_2e/kg of jam).

The major constraints encountered in applying carbon footprinting to tropical regions relate to the considerable effort needed for data collection and the high level of expertise needed to estimate the GHG emissions related to land use change.

Sensitivity of Carbon Footprints to Difference in Method and Data Set

The carbon footprints calculated according to PAS 2050 were used as benchmark data to explore the elements of subjectivity and uncertainties inherent in carbon footprinting. Of particular concern were the impacts of utilizing data from different data sets, the assumptions required to calculate the emissions from land use change and the sensitivity of the final footprint value to the inclusion of key variables such as land use change (LUC), emissions from capital goods, soil carbon stocks, and so on. By considering the impact of including or excluding different variables it is possible to gain some appreciation as to how different the results from different carbon accounting methodologies will be.

Results show that the overall carbon footprint of a product will vary enormously according to the accounting methodology used. Of particular importance is the treatment of emissions related to land use change. Where land use change occurs in tropical countries, this value is likely to dominate the footprint, and so its inclusion in any footprinting methodology will have a major impact on the final results. In addition, there are major uncertainties associated with the calculation of emissions related to LUC. Even though the International Organisation for Standardisation (IPCC) provides detailed guidance on how to calculate LUC emissions, there remains significant room for error and manipulation in these calculations. Of particular concern are the large-scale aggregated descriptions of different forest types in different countries, and the uncertainty surrounding their carbon content.

Interestingly, the very technical nature of the IPCC guidelines for calculating emissions from LUC can engender a false sense of confidence in their accuracy. This is aparticular risk for analysts who did not visit the country of concern and had no specialized forestry knowledge. In reality, characterizing existing land use in tropical countries can be difficult even after a site visit, especially when some of the forests are degraded. This task becomes even more difficult if there is no natural vegetation left in an area and analysts are required to "guesstimate" what natural ecosystems may have existed prior to conversion to agriculture. It is unfortunate that one of the key contributors to the carbon footprints of food items is also one of the most difficult to quantify. This misfortune is worsened by the potential inequity of accounting only for recent land use change in carbon footprint, which places a far greater burden on tropical developing countries than on developed countries that were largely deforested decades or centuries ago.

The impacts of LUC on a product's carbon footprint are maximized if the worst-case situation is assumed. For all of the case study examples considered, the inclusion of the worst-case LUC led to a massive increase in the footprint. This reflects the differences between the emissions from LUC in the case study countries. In Zambia LUC emissions calculated according to PAS were much lower than for the worst-case scenario (Malaysia); and in Mauritius, where no LUC emissions occurred, the inclusion of data from the worst-case situation resulted in a massive increase in the carbon footprint.

The inclusion of certain other variables in the footprint also produced some significant changes in the overall result—such as loss of soil carbon due to soil management or a change in the electricity emission factor—but none was as great as those factors relating to LUC. However, where carbon footprints are calculated with methods that do not require the inclusion of LUC emissions, the relative importance of these other variables will increase.

Recommendations for Development-Friendly Carbon Footprinting

Recommendations to improve the utility of determining the carbon footprints of food products derived from developing countries are grouped in four categories.

Land Use Change

1. Work to find an equitable solution to the inclusion of emissions from land use change in carbon footprints.
2. Develop better databases of land use and emission factors for developing countries.
3. Develop data sets that report the worst-case situation for regions rather than globally.
4. Consider including the benefits of the increased carbon sequestration that occurs above and below the ground in tree and bush crops.

Information and Data

1. Develop emissions databases for a range of factors at the level of agri-ecological zones, rather than countries or regions.
2. Make relevant data more accessible to analysts in less developed countries.
3. Provide training and support to farmers and business people in record keeping, as the collection of better data in-country will reduce the need to utilize generic data sets.

Calculation and Communication

1. Actors responsible for commissioning carbon footprints should be obliged to publish their calculations and assumptions in a publicly available database before they use or communicate the results in any way.
2. When discussing carbon footprints, users should declare the intensity of the data collection that accompanied their calculation. This should include a statement as to whether or not any primary data were collected in the country of concern.
3. The subjectivity and uncertainty inherent in calculating carbon footprints should be widely recognized.
4. Developers of footprint methodologies should consider including GHG emissions from capital inputs.

5. In communicating results to consumers, some explanation of the makeup of the footprint should be given (such as percentages of the overall footprint that occurred on the farm, from land use change, processing, transport, and use).
6. Rather than simply aggregating results for one product or commodity into a single footprint, analysts should encourage and reward members of the supply chain to innovate to reduce their specific carbon footprints.
7. In terms of innovation in the food chain, it is important to note the demotivating effect that dominant and intractable factors such as land use change and air freight can have on small farmers and businessmen.
8. Low-cost approaches to calculation and certification should be developed.

General Development

1. Work to enhance yields of crop per unit of input resource, as this will reduce the overall carbon footprint of the product.
2. Encourage the processing of foods in developing countries in order to gain carbon efficiencies from labor and energy.

CHAPTER 1

Introduction

Background to the Study

Carbon accounting and labeling are new instruments of supply chain management and, in some cases, of regulation that may affect trade from developing counties (Brenton et al., 2009). These instruments are used to analyze and present information on greenhouse gas (GHG) emissions from supply chains with the hope that they will help bring about reductions of GHGs. The designers of these schemes are caught in a dilemma: on one hand they have to respond to policy and corporate agendas to create new ways of responding to climate change challenges, while on the other they rely on very rudimentary knowledge about the actual GHG emissions emanating from the varied production systems that occur around the globe. This is because the underlying science of GHG emissions from agricultural systems is only partially developed; this is particularly true for supply chains that include activities in developing countries (Edwards-Jones et al., 2009). As a result of the pressures placed on designers and users of carbon accounting and labeling instruments, who are predominantly based in industrialized countries, there is a risk that carbon accounting and labeling instruments will not adequately represent production systems in developing countries.

This report seeks to examine the potential for emerging carbon accounting and labeling schemes to accurately represent the production systems in developing countries. In order to achieve this it includes analyses of typical problems that may occur if the characteristics of developing countries' production systems are not taken into account properly. By doing this, the report provides relevant and necessary scientific data that illustrate potential problem areas that, if not addressed, may lead to developing-country carbon efficiencies not being given proper credit.

Objectives

The main objectives of this research are as follows:

- To summarize and compare different schemes that have been devised to communicate the levels of greenhouse gas emissions from food products
- To determine the ease with which primary data and emission factors can be collected concerning food products from less developed countries
- To calculate the carbon footprints of chosen tropical commodities and assess the variation that arises when different guidelines are followed
- To assess the difficulties that less developed countries may have in meeting the demands posed by different footprinting schemes
- To provide recommendations for development-friendly carbon labeling and accounting based on the information collected

Approach

A review of existing case studies highlighted the need for collection of primary data related to tropical food products in developing countries; few existing studies offer life cycle or carbon footprint analysis of tropical products, and where these studies do exist the basic data provided are often limited. To counter this lack of data, the approach taken by this study required collection of detailed production and processing information and analysis of primary data for two products from developing countries. These data enabled a transparent and thorough carbon footprinting analysis to be undertaken, thereby reducing reliance on secondary datasets and making as few data "assumptions" as possible. Furthermore, by carrying out data collection firsthand, it was possible to assess the time and resources needed to calculate an accurate carbon footprint.

The two products chosen for analysis are sugar and pineapples. These products have very different production and processing systems, and both contribute significantly to a number of developing countries' export incomes. Extensive data were collected in the main production areas of Zambia and Mauritius, with the cooperation of a number of producers and processors. Analysis of data from field to import gate is presented here using the PAS 2050 carbon footprinting method (BSI, 2008a). This method has been chosen as the baseline for calculations here, as it is currently the only method with detailed guidelines published. Furthermore, a number of other schemes have reported that they are using PAS 2050 as the baseline for developing their own footprinting methods. It must be noted that, while this report does offer a critique of carbon accounting methods in general, these are in no way an explicit criticisim of PAS2050.

As the specific focus of this analysis is on carbon footprinting, calculations focus on the emission of greenhouse gases (GHGs) from the production systems. Other environmental and socioeconomic impacts are associated with the production of agricultural products, but they are not considered here; however, their importance should also be borne in mind by carbon footprint designers and users.

Structure of Report

This report begins with an analysis of current carbon labeling schemes as well as some of those in development, detailing as much up-to-date information about the methodologies as possible at the time of writing. A review of available data and emission factors pertaining to carbon footprinting is presented in Chapter 3, highlighting major knowledge gaps and their resulting implications for carbon footprint calculation of products originating in less developed countries.

Results from case studies of sugar and pineapples in Zambia and Mauritius are presented in Chapter 4, with their carbon footprints analyzed according to PAS 2050 guidelines. Chapter 5 explores and discusses the major areas of uncertainty and subjectivity within these footprint calculations, followed by an analysis of the impact of key variables that may differ between carbon footprinting methods. The report concludes with a series of recommendations for creating development-friendly guidelines for carbon footprinting, based on the findings of the research carried out here.

CHAPTER 2

Description of Ongoing Carbon Footprinting Initiatives Around the Globe

Summary

A number of product carbon footprinting methodologies are currently being developed. These tools for calculation and communication include nationally and internationally recognized standards, as well as those established by supermarkets. While some have been launched as consumer-facing product labels, others are in the early stages of standards and guidance formation. This chapter presents a summary of each footprint mechanism as reported to date, as well as a comparison of the different methodologies. Countries with standards mentioned here include the United Kingdom, Germany, France, Switzerland, Sweden, New Zealand, United States, Japan, Korea, and Thailand. The standards reported here will be considered again in Chapter 5, to assess how their different methods affect the final footprint calculation of tropical food products.

Current Carbon Labeling Methods and Schemes

The framework for carbon footprinting is provided by life cycle thinking and existing methods for Life Cycle Assessment (LCA). However, the needs of supply chain carbon footprints are not fully met by either the existing standards for LCA (as prescribed by ISO) or by standards for company greenhouse gas accounting, such as the GHG Protocol developed by the World Resources Institute (WRI). Additional principles and techniques that address essential aspects of carbon footprinting need to be developed and established for carbon accounting and carbon footprinting. Although internationally accepted standards on carbon footprinting have not yet become operational, many companies are keen to calculate and communicate the carbon footprint of their products to their consumers, many of whom are increasingly interested in the climate change impact of their consumption (Bolwig and Gibbon, 2009). This is why new methods for carbon footprint calculations are currently being developed by various organizations, businesses, and governments. While these responses to climate change are to be welcomed, the requirements of the different stakeholders can lead to inconsistency in different carbon accounting schemes, which in turn provides limited confidence in results and comparability of studies.

An example of mandatory carbon reporting is the EU Biofuels Directive. Here, biofuels used for compliance with regulatory requirements must comply with environmental sustainability criteria, namely (i) they must lead to at least 35 percent carbon savings; (ii) they must not be produced on land with high carbon stocks; and (iii) they must not be produced on land with high biodiversity value (Brenton *et al.*, 2009). This methodology enables producers to calculate their carbon footprint using a list of default emission values; but where a producer feels their production is more carbon efficient, they may calculate their footprint using their own data and the LCA method defined in the directive.

Overall, because of the international nature of supply chains, most stakeholders agree that there is a need for an international standard for to be developed. Although organizations such as ISO and WRI have started work on this, the resulting standards will not be available for some time. In the meantime, several accounting schemes and methods are emerging, many of them driven by businesses wishing to compete on "green" credentials and achieve and document emissions reductions in their supply chains. Some stakeholders feel that even if an international standard were developed, there might still be demand for more specific requirements that cannot be agreed upon internationally, leaving room for a range of standards at the national or business level.[1] Different schemes might emerge as a result of differing views on how to conduct the measurement of GHG emissions or through differing strategies on how to communicate these measurements to consumers. This diversity of need is evident from a review of the emerging carbon accounting schemes. Some of these calculate and communicate greenhouse gas emissions numerically, whilst others attempt to guide the consumer to supposedly "climate friendly" products without providing precise figures. Further details on some of these currently emerging carbon accounting methods and labeling schemes are provided below.

PAS 2050 and the Carbon Reduction Label, UK

PAS 2050 (Publically Available Specification 2050) was published by British Standards at the end of 2008 (BSI, 2008a). Its development was cosponsored by the Carbon Trust (an independent company set up by the UK government in 2001) and the UK government Department for Environment, Food, and Rural Affairs (Defra). A PAS is a "fast track" standard, which may be used as the basis for a proper British Standards guideline at a later stage. To date, it is the most detailed and comprehensive guideline for the calculation of product-based carbon footprints publicly available. In addition to the main PAS 2050 standard method, there is also a guideline document to help businesses implement the standard by offering specific and practical guidance (BSI, 2008b). The PAS 2050 method is used to calculate carbon footprints that can be used by companies to guide their own management activities, or they can be communicated to consumers via a carbon label awarded by the Carbon Trust. This carbon label communicates the greenhouse gas effect of a product by giving a single figure of CO_2 equivalents per functional unit of analysis (e.g., a kilogram of food product or a liter of drink).

The PAS 2050 method covers the whole life cycle of a product, including the use phase and emissions from land use changes that have taken place since January 1, 1990. Some items are not included in the analysis, such as capital inputs, consumer shopping trips, and the transport of employees to their workplace. Changes in the carbon content of agricultural soils (either as sequestration or emissions) are not included, except for emissions resulting from direct land use change. Data quality rules detail where primary data should be used in calculations and suggest data sources for secondary data.

Products with published carbon footprints developed according to the PAS 2050 guidelines include Walkers crisps, Boots Botanical Shampoos, potatoes and orange juice (Tesco), and Cadbury's dairy milk chocolate.

A company that prints the Carbon Trust carbon label on a product commits to an emission reduction across the whole of that particular supply chain within two years. If it fails to achieve this, it will lose the right to use the label. This means that any product can receive the carbon label, which is seen as an encouragement for all businesses to reduce the carbon footprints of their products. In contrast, the Migros and Swedish approach to labeling (see below) only award a label to the most climate-friendly products within a product group in order to stimulate competition for the label. The PAS 2050 will be reviewed and updated in 2010.

International Organisation for Standardisation (ISO)

ISO has started to develop a new international standard for carbon footprinting of products and services (ISO 14067). The standard will consist of two main parts on quantification and communication, respectively. The standards are expected to be completed in 2011. A first draft of the ISO standard is expected to be made available for comment by mid-2009.

World Resources Institute and World Business Council for Sustainable Development

The WRI and World Business Council for Sustainable Development (WBCSD) have announced their intention to develop two new standards for product and supply chain greenhouse gas accounting and reporting. These institutions have previously developed the most widely used standard for the measurement and management of greenhouse gas emissions at the company level (GHG Protocol). The new standards will include guidelines on life cycle accounting and reporting, both at the product and the company level. The new standards are necessary to enable the inclusion of the whole life cycle of a product and to enable businesses to include the whole supply chain beyond their own operating boundaries. This will allow them to achieve emission reductions within the whole supply chain, leading to more sustainable consumption patterns.

The development of the new standards will be a multistakeholder, consensus-based process involving businesses, policymakers, NGOs, academics, and other experts and stakeholders from around the world. Currently, over 300 stakeholders are involved. Various technical working groups are currently looking into specific accounting topics (e.g., boundary setting and allocation, data collection and quantification of emissions). Draft guidelines will be reviewed by a stakeholder advisory group and made available for public comment before being finalized.

The current timeline of the project suggests that draft guidelines will be available in late 2009, pilot testing of draft guidelines will take place in late 2009 or early 2010, and the final guidelines will be complete in December 2010. It is likely that a WRI/WBCSD standard for product accounting will have widespread international uptake.

New Zealand Greenhouse Gas Footprinting Strategy

During 2007 the New Zealand Greenhouse Gas Strategy for the land-based sectors was initiated by partnership of the Ministry of Agriculture and Forestry (MAF) and the primary sector. The background to this development was the desire to strengthen and position New Zealand's land-based primary sectors to respond to the significant and increasing pressure exerted by key export markets for information on the carbon footprint of their products.

The aims of the strategy do not include consumer information and education via a product-based label. Rather, the strategy is a response to an increasing demand and desire for:

- more proactive involvement in international efforts for developing international guidelines for carbon footprinting
- providing primary producers with the means to assess their carbon footprints
- addressing gaps in current scientific knowledge and data availability

- identifying weaknesses and threats to New Zealand's product and production profiles
- capitalizing on business opportunities for exporting products with a low carbon footprint

Sector-specific approaches to carbon footprinting of primary products, including the whole life cycle of products, are currently being developed for 12 sectors, covering over 70 percent of New Zealand's primary sector exports. The final methodologies will be pragmatic approaches that can be applied by business. The methodology used in developing these guidelines is consistent with ISO guidelines for LCA and PAS.

The first sector studies to be finished will be for wine and kiwi fruit. At that time, guidelines for growers will be published and will contain guidance on GHG reduction options.

Agency for the Environment and Energy Management (ADEME), France

ADEME, the French Agency for the Environment and Energy Management, supports pilot projects with the aim of learning by doing. It works with retail organizations and develops databases and good practice guidelines with the aim of providing consumers with information on environmental impacts of the products they are buying, allowing comparison between products and harmonizing communication practices across France (for example, the supermarkets Casino and Leclerc currently use different calculation and communication methods, see below).

ADEME wants to develop carbon footprinting information alongside other environmental impacts such as biodiversity (i.e., the approach will be based on multiple criteria). The guidelines for carbon footprinting were due to be finalized at the end of April 2009 (according to Edouard Fourdrin, Département Eco-Conception et Consommation Durable, ADEME).

Their database committee will develop and hold a database as a reference, especially for food products. Secondary data will be provided by this database. The general platform for carbon footprinting, once developed, will be freely accessible. There will be 16 specified groups working on different product areas, one of which will be food and pet food. These working groups had not been launched as of March 2009, but they intend to produce methods for each of the product groups in due course.

The timeline for the project is:

- The general platform runs from May 2008 to December 2010.
- The methodological platform runs from September 2008 to September 2009.
- The specified working group has been running since spring 2009.
- The database governance committee starts work in March 2009.

As of January 1, 2011, environmental labeling of consumer products will progressively become mandatory in France. This means that the method will have to be fairly simple and not too time-consuming to be implemented by all types and sizes of business, and standard databases holding secondary data will need to be developed by then.

Casino, France

The French supermarket chain Casino started working on carbon footprinting in 2006. Although they also consider a range of other environmental issues (e.g., biodiversity loss and consumption of fossil fuels), they focus on greenhouse gas emissions, due to their importance. The method they use was developed by the environmental consultancy Bio Intelligence Services. In developing the calculations, Casino obtained technical and financial support from ADEME, some of whose databases were used in the calculations.

Life cycle stages included in the calculation are agricultural production, manufacture, transport to Casino warehouses, packaging, recycling, and transport to consumers' homes. The use phase in the consumers' homes is not included due to the difficulties in estimating what the consumer might do. The functional unit used is 100 g of product, rather than the product size as sold in the supermarket. A software tool is used by suppliers who can enter their data directly into the tool. Where there are several suppliers for one ingredient, the average distance is used for the calculation of emissions from transport.

Because data on agricultural processes are not always readily available, Casino encourage suppliers to carry out research to make the information available. In the meantime, generic data and data from life cycle analyses carried out in France or elsewhere are used to assess the environmental impact of production and processing.

To date, Casino has focused on their own brand products. The areas identified as having the greatest impact on the carbon footprint are consumer travel to shops, refrigerant use, and transport of goods to supermarkets. As a consequence, in order to reduce their environmental impact, Casino has introduced tracking systems to reduce emissions from goods transport as well as ecofriendly design for packaging. They have also decided not to build more out-of-town superstores, but instead increase the number of smaller convenience stores closer to the consumer in order to reduce the impact from consumer travel.

Casino prints carbon labels on the products it has analyzed.[2] It found that consumers want a figure for carbon emissions because they feel that an exact figure proves that the method applied is scientific and is the result of a serious calculation process. However, consumers also need to be told whether a certain product is "good" or "bad" in terms of climate change impact; so in addition to the actual figure in CO_2 equivalents, they also print a scale of carbon footprints across product categories, with the position of the present product sited along the scale indicating the impact of that particular product in comparison with other products. Moreover, they give information about recycling opportunities and try to educate consumers as to what they can do to reduce greenhouse gas emissions.

The method used by Casino is currently being reviewed and is changing rapidly. There are plans to align it more with PAS 2050 in the future (according to Rasmus Prieß, THEMA1, Project Leader PCF Pilot Project Germany).

Migros, Switzerland

Migros is a Swiss supermarket chain. Carbon footprints are calculated using ISO-consistent LCA methods with Ecoinvent as the underlying database.[3] The whole life cycle of products is included in the calculations. The LCAs are carried out by the not-for-profit organization Myclimate, while the actual label used to communicate climate change impacts of products is certified by the organization Climatop.

Migros do not to label all products; rather, they only label those products in product categories that are at least 20 percent more climate friendly than the other products analysed. These are then termed “climate champions.” The label of climate champion is expected to encourage companies to innovate and reduce GHG emissions in order to have as many climate champions as possible. The label does not display the exact carbon content, but provides the information that the product is more climate friendly than comparable products.

So far, Migros has analyzed over 60 products, but has only labeled eight products as climate champions. For some product categories, no climate champion could be labeled, but important lessons have nonetheless been learned about where in the supply chain emissions reductions can be achieved. In their experience, the label is too young to have significant consumer recognition yet, so any impact it might have on consumer behavior remains to be seen. Detailed information on product comparisons is available on the Migros website.[4]

An example of a food product labeled as a climate champion is sugar produced from organically grown sugar cane from Paraguay. This product has emissions that are about 40 percent lower than the average sugar sold by Migros. Six different sugars were analysed, including sugar cubes, granulated sugar, sugar from sugar beet, sugar from sugar cane, organic sugar, and conventionally grown sugar. The countries of origin were Switzerland, Germany, Paraguay, and Columbia.

Migros would like to expand the use of their method to all businesses so that there will be a healthy competition for the climate champion label.

Leclerc, France

Leclerc, a French supermarket chain, has labeled all of its food products based on generic data on broad product categories. The total carbon footprint of a shopping basket is communicated to the consumer on their till receipt.

The method for calculations was developed by the consultancy Greenext and includes production, distribution, and consumption of goods. The method is simplified in order to allow mass labeling of almost all products in the food department. Calculations are based on generic data representative of the French market, which are then refined with data on the impact of stores and characteristics of packaging materials.

Transport emissions from factories to stores will be included in the future. Products are defined as product groups with similar characteristics in terms of composition, manufacture, and representativeness of the market. The generic product definitions are subject to material and energy balances, calculated using national regulations, European studies, interprofessional data, national data, and statistics.

The method will be further developed to include other environmental impact categories such as energy and water use or toxicity impacts.


E.LECLERC WATTRELOS
POINT ACCUEIL
TEL : 03.20.20.99.99
BONJOUR,

Caisse 040-0090 18 avril 2008 17:08
Ticket 18/04/08 0 1547 05200

* BLANC DE POULET	1.58
* SAUCISSES	1.39
* YAOURT VANILLE	2.50
* GÂTEAU	1.83
* MOUTARDE	1.32
* PUR JUS D'ORANGE	1.60
NETTOYANT CUISINE	1.70
COLORATION CHEVEUX	11.10
DENTIFRICE	1.10
Total 9 articles	24.12
Soit en franc : 158.22	
(1 euro = 6,55957 francs)	
Especes	24.12
Rendu	0

MERCI
DE VOTRE CONFIANCE
A BIENTOT !

Le bilan CO_2 de mes courses est de :
13,38 kg eqCO_2 (1)

Plus le chiffre est faible, mieux c'est pour ma planète !!
Pour en savoir plus, RDV sur le stand à l'entrée du magasin ou sur le site
www.jeconomisemaplanete.fr

No detailed information on the methodology and database used is currently available.

Ministry of Economy, Trade, and Industry (METI), Japan

The Japanese method for carbon footprinting is in the final stages of development, with an extract of the draft document available in English. The basis of the methodology is LCA, and it is intended to be developed consistent with ISO developments on carbon footprinting. Carbon footprinting will be mainly targeted at food products and necessities. A carbon label will communicate carbon footprints in units of CO_2 equivalents to consumers. The methodology will be further refined during a trial period of carbon labeling, which involves about 30 companies (Ikezuki 2008). Carbon footprinting, including the communication of results to the consumer, forms part of the Japanese government's action plan for achieving a low-carbon society; JEMAI, the Environmental Management Association for Industry, is organizing the carbon footprinting system during its trial period (Ikezuki 2008).

Existing emission factor databases held by the Japanese government will be expanded and updated. It is hoped that this database will hold reliable, universal, widely coverable data that will allow both operational convenience and confidentiality of company information. Existing datasets are available through the development of the EcoLeaf label, which was introduced in 2002. EcoLeaf is an environmental declaration based on LCA methods, including the full life cycle of a product. Product Environmental Information Data Sheets are made publicly available for labeled products, showing the results of the inventory analyses and impact assessments for all life cycle stages. Datasets available through EcoLeaf are to be used for carbon footprinting calculations. However, little information is available on how exactly the EcoLeaf calculations were carried out (e.g. which databases were used).

The draft methodology available in March 2009 is not as detailed as PAS 2050, and some important decisions are still outstanding—such as whether greenhouse gas emissions from livestock and other agricultural processes should be included in the calculations, the preferred allocation methods, and cutoff criteria for permissible omissions from the calculations. Capital inputs and greenhouse gas emissions resulting from land use change are currently not included (according to Chie Nakaniwa, JEMAI, Japan). No rules for data quality are set out in the current draft. In the case of multiple suppliers of raw materials, companies are allowed to use primary data collected from the main supplier as secondary data for the other suppliers where it is too difficult to collect primary data from all suppliers. This differs from PAS 2050, which recommends using a "representative" sample. A revised version of the draft methodology should become available in June 2009 (according to Chie Nakaniwa, Environmental Management Association for Industry JEMAI, Japan).

The timeline for the project is:

- exhibition of trial products with a carbon label: December 2008
- national pilot project for building a carbon footprint system: 2009–11
- trial labeling of products: from April 2009

KRAV and Svenskt Sigill, Sweden

The aim of the Swedish climate labeling initiative is to create a system which will reduce the negative impacts of greenhouse gas emissions from the food system, encourage competition for food businesses, and allow consumers to make climate conscious choices. The project is a joint initiative, including the Federation of Swedish farmers, dairies, a cereal cooperative and two existing labeling bodies. The leading organizations are KRAV (similar to the British Soil Association), an association that develops organic standards and promotes the KRAV label; and Svenskt Sigill (Swedish Seal of Quality), the Swedish quality label for assured food that certifies food from farms following strict criteria for safe food, animal welfare, responsibility for the environment, and a vivid landscape (according to Anna Richert, Svenskt Sigill).

The label will include most life cycle stages, including agricultural production, distribution, packaging, and imported products. The use phase will not be included. Initially, only products with a low degree of processing will be included.

During the project, criteria will be developed that will help assure that a producer has made improvements in terms of greenhouse gas emissions. The baseline for this is determined by a scan of existing LCA analyses and knowledge about carbon emissions, energy use or other production data that can be useful. As long as certain criteria (yet to be defined) have been made—for example, there has been a reduction in the use of nitrogen fertilizer—a product can get the label. This will not involve any new calculations of exact carbon footprints.

There is no need for the background documents to be fully standardized and fully comparable, because this approach does not attempt full and precise carbon accounting; rather, it will entail a scan of production systems and their effects on carbon emissions as well as potential improvements. The standards will be worded as general standards that regulate activities affecting climate change within production and transport. The final product of the project is a set of standards for climate marking of food that, on average, gives a 25 percent lower climate impact than the reference. This will be measured by the monitoring and follow-up system that is being created within the project.

The label will not inform consumers about the absolute greenhouse gas emissions from the life cycle of a product, that is, there will be no absolute figure of CO_2 equivalents on the label. The aim of the label is to certify to the consumer that improvements have been made. The label will also not allow comparisons between different product categories, so it will not help consumers choose between, for example, meat and beans, but rather will help them to choose a climate-friendly product from within each category. Only the best products in each category will be labeled. So far, only Swedish products have been included. There will be no specified targets for emissions reductions associated with the label; however, the label is expected to lead to substantial emissions reductions.

The timeline for the project is:

- March 2009: criteria for fruit, vegetables, potatoes, cereals, seafood, and milk will be published
- June 2009: criteria for meat will be published
- September 2009: the labeling scheme will be launched and the first labeled products appear on the market

Blauer Engel (Blue Angel), Germany

Introduced in 1978, the Blue Angel is the oldest eco-label in the world and enjoys a high level of acceptance in Germany (more than 80 percent of Germans are aware of the label). It is awarded to companies according to defined criteria in order to reward their commitment to environmental protection. It is intended to help guide consumers to products designated as ecologically superior and thus promote more environmentally friendly consumption. As such, it is a label that marks top products, helping the consumer to choose environmentally friendly alternatives. The German government's Federal Ministry for the Environment and Federal Environment Agency, together with the Environmental Label Jury, will further develop the existing label to highlight climate-friendly products.

Pilot projects are underway to develop criteria for ten product groups felt to be particularly important and climate-relevant, such as refrigerators, washing machines, and television sets, with the first label planned for the spring of 2009. A further 90 product groups are expected to be added over the next three years. Food products are not yet included, and the underpinning method will be based on PAS 2050 (according to Ulf Jaeckel, Federal Ministry for the Environment).

Republic of Korea

A carbon label is being developed in the Republic of Korea at the moment and will be finalized in the near future. On April 15, 2009, a carbon label was certified for 23 products from 12 companies (according to Dr Ik Kim, Korea Eco-Products Institute, Seoul). No details on the methodology used are currently available in English, but an English website is currently under development.

Thailand

Work on the Thai carbon labeling scheme has just started. It will be a three-year process, and the method will be developed in cooperation with the EU. It is anticipated that the method will be very similar to PAS 2050, if not the same (according to Ms Kirana Chomkhamsri, Institute for Environment and Sustainability, European Commission).

TÜV Nord, Germany

TÜV Nord, one of Germany's largest technical service providers, offer an inspection and certification service for "carbon-neutral" products. This service is a version of the WRI/WBCSD GHG Protocol, modified with regard to the specific characteristics of product certification. As it certifies carbon neutrality, the method includes the calculation of carbon credits and carbon offsetting. This is different from PAS 2050, which excludes any offsetting in order to highlight the actual impact of a product.

At the moment, the standard that is available is still a draft; we do not know when it is expected to be finalized. No definitive rules on where to set system boundaries are expressed in the draft. All Kyoto GHGs with the latest global warming potentials according to UNFCCC are to be included. The sources and data aggregation methods used need to be "reliable, complete and traceable," and permissible data sources for emission factors, for example, include IPCC, GHG Protocol, UNFCCC, and EU-ETS. At least 95 percent of the total emissions should be included. Where the quantification of certain emissions is considered to be not material, not technically feasible, or not cost effective, the decision might be taken to exclude these emissions; however, the client is expected to provide a proper justification for this exclusion.

In the case of details not being covered by the standard, the client is referred to the GHG Protocol and the international relevant ISO standards.

Soil & More International, a company based in the Netherlands that runs large-scale composting sites in developing countries to produce high quality compost, carries out emissions reduction projects and contributes to the development of sustainable methods for the management of soils and food crops. They also conduct GHG assessments of companies and products according to the TÜV Nord standards. Their composting technology which uses unwanted waste and plant and animal material that would otherwise produce methane during landfill is certified as an emissions reduction project according to UNFCCC. Carbon footprints calculated by Soil & More include the supply chain from cultivation in a developing country up to the retail store in Europe. The calculation includes an estimation of the total GHG emissions occurring from a supply chain during a particular year in order to allow offsets to be purchased.

carboNZero, New Zealand

This is not a method in itself, but a provider of tools and resources to measure, manage and mitigate the greenhouse gas emissions of both households and businesses. CarboNZero certification is available and requires a commitment to reduce emissions at the source. Access to guidelines, tools, and certification for businesses are subject to the payment of a registration fee, certification fees, and audit fees. Calculators for household, travel, and tourism and schools calculators are free. The method is consistent with PAS 2050.

Patagonia Clothes, United States

Patagonia Clothes provides information on energy consumption, greenhouse gas emissions, and waste generation of five items of clothing on their website. The method used for the calculation of greenhouse gas emissions is the WRI/WBCSD GHG Protocol. The calculations only consider transportation and facility energy use in the product supply chain, mainly—if not exclusively—based on energy use.

European Ecolabel (Eco-Flower)

Currently, the possibility of including carbon footprinting within the European Ecolabel is being considered as part of a revision of the label in 2009. The revised Ecolabel might also be available to the categories of food and drink which so far have been excluded. An Excel spreadsheet toolkit was developed as a simplified model for some product groups covered by the Ecolabel. The project report and toolkit are currently published for consideration and discussion within the EU Ecolabel community only. This is being done with the aim of making decisions on how best to develop this issue in relation to the EU's multicriteria labeling scheme.

One of the reasons why the European Commission has so far not become further involved in the issues of carbon footprinting and carbon labeling is that none of the currently emerging schemes in Europe (such as PAS 2050, ISO, Ademe's Repository of Best Practice) have an agreed-on common approach that would allow for the development of mandatory policies.

Stop Climate Change, Germany

This German initiative (operated by AGRA-TEG Agrar- und Umwelttechnik GmbH Göttingen, a spin-off of the University of Göttingen) includes the calculation of emissions, verification of results, application of identified emissions reductions strategies and the communication of these activities via a label that certifies carbon neutrality achieved through the purchase of carbon credits. The aims of the initiative are to identify, quantify, and document GHG sources; define opportunities for emission reductions; raise awareness within the business; and communicate the commitment of the business to the wider public. Another aim is to generate new data on GHG emissions of products, services, processes, businesses, sectors, and industries and to stimulate a continuing improvement process through benchmarking.

The developers of this standard claim that their system is relatively easy to apply and at the same time guarantees the inclusion of all relevant GHG emissions. The label "Stop

Climate Change" is relevant for products, while businesses can be labeled "climate friendly business according to the Stop Climate Change standard."

The identification and implementation of reduction measures are an integral and mandatory part of the standard. Unavoidable emissions have to be offset by purchasing certified carbon credits. These measures are audited each year. The scheme operators recommend offset through projects with the Gold Standard rating, which is an independent quality seal for Clean Development Mechanism (CDM) and Joint Implementation (JI) projects.

Emission factors used should be those employed by the EU emissions trading scheme as far as possible. Where exact data on activities are not available or it is too time-consuming or costly to determine them, assumptions following a worst-case scenario can be made. Some detail on the methodology is available on the website www.stop-climate-change.de, where it suggests that ISO 14064-3 is used as a basis for the methodology.

PCF Project and PCF World Forum, Germany

The Product Carbon Footprinting initiative does not develop a new standard for carbon footprinting, but evaluates current initiatives and fosters international dialogue in the absence of an internationally agreed standard. Its aims are (1) to test and evaluate the practical application of the current and evolving methodologies for carbon footprinting (based on ISO norms for LCA) by working with several companies to calculate product carbon footprints; (2) to give recommendations for the further development of methodologies based on the findings from the case studies; and (3) to discuss how to best present carbon footprinting results in the form of labels. The project is run by the Institute for Applied Ecology (Öko-Institut), Potsdam Institute for Climate Impact Research (PIK), and the think/do tank THEMA1 and WWF.

The PCF World Forum is a joint platform set up to foster and facilitate dialogue between international initiatives on how to assess, reduce, and communicate the impact of goods and services on the climate. Its aim is to promote the development of internationally accepted common standards.

Wal-Mart, United States, and ASDA, United Kingdom

In 2007 Wal-Mart and the Carbon Disclosure Project began a trial climate change reporting scheme with the suppliers of seven major retail products: DVDs, toothpaste, soap, beer, milk, vacuum cleaners, and soda products (Carbon Disclosure Project, 2009a). The purpose of this scheme was not to develop consumer-facing carbon footprints, but rather to encourage energy use reporting from suppliers, with the specific aim of reducing energy use and removing nonrenewable energy from products (Wal-Mart Stores Inc., 2009a). The results of this trial are yet to be published and the exact carbon footprint methodology followed by suppliers has not been reported. More recently, a call has been made to Wal-Mart suppliers, inviting them to report supply chain GHG emissions and reduction targets from November 2009 (Carbon Disclosure Project, 2009b).

Similarly, Asda, the British subsidiary of Wal-Mart, has begun work with suppliers of fresh foods (including eggs, milk, potatoes, lamb, and chicken) to map the embedded carbon in their supply chains (Asda, 2009). The purpose of this footprinting activity is to identify elements of the supply chain which are resource-intensive and can therefore be improved upon to reduce their carbon emissions. Through this scheme, dairy farms are now working to calculate their carbon footprint and identify ways of reducing it using a toolkit provided by Asda (Wal-Mart Stores Inc., 2009b; Asda, 2009), but the exact footprinting methodology is not reported. These two examples suggest that carbon footprinting and subsequent reduction schemes may become preferable or even mandatory for suppliers of large supermarkets in the future.

Conclusion

Although there are several schemes that are already being implemented at the time of writing, the British PAS 2050 is the only finalized methodology that has calculation mthods in the public domain (Table 2.1). This is why this methodology is used as a benchmark for the analysis of tropical commodities presented in Chapter 4. The method implemented by the Swiss supermarket Migros is a standard LCA and therefore does not constitute a new methodological approach. The methods employed by the French supermarkets Casino and Leclerc are not documented in enough detail to attempt an analysis of the case study data collected for this project according to these methods, although the Casino method will be aligned with PAS 2050 during its current revision. Repeated attempts by the authors of this report to obtain more detailed information on the schemes used by the two French supermarkets (via direct email contact and through the websites) were unsuccessful, which highlights the reluctance of some of the businesses involved in carbon footprinting to disclose their exact methods to scientific and public scrutiny.

Other schemes are currently being developed and will be finalized in the near future (Table 2.1), including the Japanese and French government schemes. However, these methods are not available in enough detail at the time of writing to use them for any kind of comparative analysis. The Japanese scheme is the furthest developed at the moment, but important decisions—especially for agricultural products—are still outstanding. Table 2.2 illustrates availability of methodological details for several carbon footprinting initiatives.

The fact that there are several schemes emerging at national levels and developed by different business stakeholders might lead to problems for internationally operating companies in the future. At an international conference on product carbon footprinting in February 2009, several business representatives expressed their concerns about meeting

Table 2.1: Summary of information available on different carbon footprinting methodologies

Methodology	Current status	Approach	To be finalized by:
PAS 2050	Finalized	PAS 2050	
ISO	In development	?	2011
WRI/WBCSD	In development	?	2010
New Zealand Greenhouse Gas Footprinting Strategy	In development	PAS 2050/ISO	From 2009
ADEME	In development	Similar to PAS 2050	2009
Casino	Finalized	Will be aligned with PAS 2050 in future	
Migros	Finalized	Standard LCA	
Leclerc	Finalized	Generic, broad approach	
Ministry of Economy, Trade and Industry (METI), Japan	In development	Similar to PAS 2050	2009–11
KRAV and Svenskt Sigill	In development	Using existing LCAs	2009
Thailand	In development	Similar to PAS 2050	2011
Korea, Rep.	In development	?	?

Table 2.2: Comparison of methodological approach, data requirements, and data sources for some carbon footprint schemes highlighting problems in indentifying methodological details

	Carbon footprint scheme					
Data	**ISO LCA**	**PAS 2050**	**TÜV Nord**	**Soil & More (modified TÜV Nord)**	**Casino**	**Japan (METI)**
All Kyoto GHGs	Yes	Yes	Yes	Yes	?	Yes
Agricultural emissions not caused by energy use:	Yes	Yes	?	In parts	?	Undecided
N_2O emissions from organic fertilizer	Yes	Yes (use IPCC)	?	No	?	Undecided
Livestock emissions	Yes	Yes (use IPCC)	?	N/a	?	Undecided
Emissions of livestock, manure, and soils are treated as secondary data	Yes	Yes (use IPCC)	?	Yes	?	?
Land use change emissions:	Yes/no	Yes (1990)	No	No	? (no)	No
Default EFs supplied for some countries	Yes	Yes (use IPCC for other countries)	No	No	? (no)	No
Always assume worst-case scenario if former land use or country of production not known	No	Yes	No	No	? (no)	No
Change in soil carbon	Yes/no	No	No	No	? (no)	No
Capital inputs	Yes/no	No	?	No	?	No
Energy use						Yes
Diesel	Yes	Yes (source of EF unspecified)	Yes	Yes	?	Yes

(Continued)

Table 2.2: Comparison of methodological approach, data requirements, and data sources for some carbon footprint schemes highlighting problems in indentifying methodological details (*Continued*)

	Carbon footprint scheme					
Data	**ISO LCA**	**PAS 2050**	**TÜV Nord**	**Soil & More (modified TÜV Nord)**	**Casino**	**Japan (METI)**
Gasoline	Yes	Yes (source of EF unspecified)	Yes	Yes	?	Yes
Electricity	Yes	Yes (use country specific EF)	Yes	Yes	?	Yes
Human energy inputs	Only if high	No	No (?)	No	?	No?
Country-specific electricity EF	Yes	Yes	Yes	Yes	?	?
Transport						
Travel of employees to/from work	Yes/no	No	?	Yes	?	?
Travel by consumers to shop	Yes/no	No	?	?	?	
All transport steps for product	Yes	Yes	Yes	?	Yes	
Sales trips	No	?	No (?)	Yes	?	?
Consumer use phase	Yes	Yes (defined according to rules page 15)	No	No (up to retail only)	No	Yes (use a standard scenario)
Waste disposal	Yes	Yes	No (?)	No	No (?)	Yes
Recycling	Mass allocation	Economic allocation	No (?)	N/a	No (?)	Yes
Refrigerant losses and other fugitive gases	Yes/no	Yes	?	Yes	Yes (?)	?

Outside services (advertising, lawyers etc.)	No	No	?	?	No	No
Functional unit	User defined depending on study	As consumed by end user	?	kg fruit at European retail	100 g of product	?
Carbon storage in products	Yes/no (not for food)	Only for (certain) non-food products	No (?)	No	? (no)	?
Carbon storage in vegetation/soils	Yes/no	No (?)	No (?)	No	? (no)	?
95% rule	Yes/no	Yes (excl. Use phase)	Exclude emissions that are not material, technically not feasible or not cost effective to analyze	?	?	Cutoff criteria to be established for each PCR
Data sources for global warming potential (GWP)	Latest GWP	IPCC	UNFCCC	?	?	Second IPCC Assessment Report (as for Kyoto)
Uncertainty assessment	Yes	Optional	Yes	No (?)	?	?
Aircraft emissions	Yes	No multiplier or other correction shall be applied (p. 7), no uplift factor	Yes (?)	?	?	?
Delayed emissions weighted over 100 year time horizon	No	Yes (equations are given)	?	?	?	?

(Continued)

Table 2.2: Comparison of methodological approach, data requirements, and data sources for some carbon footprint schemes highlighting problems in indentifying methodological details (*Continued*)

	Carbon footprint scheme					
Data	**ISO LCA**	**PAS 2050**	**TÜV Nord**	**Soil & More (modified TÜV Nord)**	**Casino**	**Japan (METI)**
Offsetting	No (very rare)	No	Yes	Yes	No (?)	?
Use of primary data	Yes (as much as possible, depends on depth of study)	For all processes/ materials owned/ operated/controlled by the organization	?	?	?	Secondary data only where no primary data can be obtained
Rounding of final reported figure	No	Yes	No (?)	No	?	?
Allocation	(1) avoid (expand/ divide), (2) mass/ energy/physical relationship, (3) economic	(1) avoid (expand/ divide), (2) economic	?	?	?	To be established for each PCR
Multiple suppliers	Attempt average	Use representative sample (PAS guide (BSI 2008b) says weighted average of random sample)	?	?	?	Use primary data from principal supplier for other suppliers

Note: "Yes/no" denotes that the decision lies with the analyst; "?" means there is a lack of information; no "?" means this is a guess based on what we know about the methodology. The shaded cells highlight areas where ISO-compliant LCA and PAS definitely differ in their approach. EF = emission factor.

the demands posed to them by different schemes introduced by different countries and supermarkets. Having to calculate carbon footprints for the same product in several different ways to be able to sell the product to different markets would represent a burden for the suppliers.

All of the schemes presented in this section are based in industrialized countries. Although there probably are some more schemes being developed or already implemented around the world, it is unlikely that any initiatives are currently led by and run in developing countries. The EU Commission has identified this as a problem and calls for stakeholders involved to consider how non-EU countries can be involved in the further development of methods (Pavel Misiga, Directorate-General for Environment, European Commission, speaking at the PCF World Forum, Berlin, 27 February 2009).

The European Commission is also working on developing an authoritative basis to ensure quality and coherence for LCA and carbon footprinting tools in order to increase comparability of results between studies and decrease the current dependence on expertise provided by a small number of consultants, databases, and contractors.

Notes

[1] The development of carbon labeling schemes mirrors the recent development of a number of other private standards within the global agro food industry. Private label food safety standards, for instance, have played an increasingly important role in high end markets such as OECD country supermarkets since the early 1990s. Pressures for differentiation (and, occasionally, counterpressures for harmonization) have been observed in such markets leading to a situation where a large number of competing standards are used today. Examples include more generic standards such as Safe Quality Food, British Retail Consortium Global Standard and GlobalGAP, and company-specific standards such as Marks & Spencer's Field-to-Fork, Tesco's Nature's Choice, Auchan's Filiere Agriculture Raisnonnee, and Carrefour's Filiere Qualite. While most standards share the same basic characteristics, each has its own detailed requirements and requires unique conformity assessment procedures. The players involved in implementing carbon labelling schemes today overlap to a large extent with the actors that have implemented private food safety standards throughout the latest two decades.

[2] For examples of products, their carbon footprints, and supporting information, see http://www.produits-casino.fr/spip.php?page=developpement_durable_infos_produits&debut_articles=15#pagination_articles.

[3] The Swiss Ecoinvent database contains international industrial life cycle inventory data on energy supply, resource extraction, material supply, chemicals, metals, agriculture, waste management services, and transport services (Ecoinvent, 2009). This is a commonly used database for LCA calculations.

[4] http://www.migros.ch/DE/Ueber_die_Migros/Nachhaltigkeit/Produkte_Labels/CO2_Produktdeklaration/Seiten/Uebersichtsseite.aspx

CHAPTER 3

Availability of Data Relevant to Developing Countries

Summary

This chapter presents a review of available data and emission factors necessary for food product carbon footprint calculation, with specific reference to less developed countries. First, a summary of relevant IPCC default data is given, demonstrating the current status of internationally recognized emission factors. These can be relied upon in the absence of more locally specific data. The chapter then explores the availability of country- or region-specific emission factors and data from other sources. A number of knowledge gaps are identified here, and implications of food product carbon footprint calculation are discussed in Chapters 4 and 5.

Introduction

The calculation of carbon footprints requires the use of secondary data in the form of readily available datasets, as well as a variety of emission factors to convert processes such as energy use into a CO_2 equivalent value. A product carbon footprint may not be accurate or representative if the data used in its calculation are not specific to local or regional circumstances. However, it is unclear whether equal data and emission factors are available for all countries and regions, particularly for less developed countries (LDCs). The purpose of this section is to report on the availability and reliability of data required by PAS 2050 (BSI, 2008a) and LCA methodologies.

PAS 2050 states that IPCC guidelines (IPCC, 2006a) should be followed for calculating emissions from agriculture and land use change, both of which are relevant to food product carbon footprinting. Where country-specific data are not available, IPCC provides default emission factors, most of which are not country- or continent-specific. The next section provides a summary of some default IPCC emission factors relevant to food product carbon footprinting, demonstrating the assumptions that may be made across carbon footprint calculations. The section following that one explores the availability of relevant country-specific data, examining whether or not data gaps are more prevalent in LDCs. The implications of data gaps and resulting assumptions are explored further in Chapter 5.

IPCC Emission Factors

Product carbon footprints should ideally be calculated using country- or region-specific emission factors. In reality, however, large data gaps exist (see next section) due to the complexity and time-consuming nature of calculating reliable emission factors. This has resulted in many practitioners relying on default emission factors such as those provided by the IPCC in their online Emission Factor Database (EFDB). This centralized database of emission factors (EFs) was created in 2000 with the purpose of enabling better-quality GHG inventory compilation, enabling countries to comply with the UNFCCC requirement for GHG reporting. Its application in carbon footprinting has since developed, with many referring to this as a source of data where country-specific values are not available.

Within the IPCC EFDB, the IPCC report that:

- *Emission factors* should reflect national/regional circumstances.
- *Emission Factors* have to be accompanied with appropriate scientific background information.
- *Emission factors* should be documented: "easy" to find and "easy" to check / compare.

(IPCC, 2002).

Despite the long-term intention of this database to provide EFs that reflect national or regional circumstances, it appears that most of those EFs reported to date are either global or "tropical" values (Table 3.1).

As can be seen from Table 3.1, emission factors applicable to this exercise that are reported in the EFDB currently have little geographic disaggregation, with uncertainty ranges being up to an order of magnitude (shown in parentheses in Table 3.1). Using these values may result in major inaccuracies within the carbon footprint. This is especially important for agricultural products, for which the largest source of production emissions

Table 3.1: Default emission factors (EFs) relevant to tropical food carbon footprinting

Emission factor description	Emission factor region/ regional conditions	Emission factor value
Indirect N_2O emissions from volatilization of synthetic fertilizer[a]	Global	0.1 (0.03–0.3) kg NH_3–N & NO_x–N/kg N applied
Indirect N_2O emissions from N losses by leaching/runoff for regions where irrigation (except drip irrigation) is employed[a]	Global	0.3 (0.1–0.8) kg N/kg N additions
Direct N_2O emissions from synthetic and organic N application to soil[b]	Global (excluding flooded rice fields)	0.01 kg N_2O–N/kg N applied
Direct N_2O emissions from drained/managed organic soils[b]	Tropical	16 kg N_2O–N/ha/yr
Direct N_2O emissions deposited from grazing animals[b]	Global	0.02 (cattle, poultry & pigs) and 0.01 (sheep and other animals) kg N_2O–N/kg N applied
CO_2 emissions from burning of field residues in croplands[a]	Global, all crops	1515 g/kg dry matter combusted
CH_4 emissions from burning of field residues in croplands[a]	Global, all crops	2.7 g/kg dry matter combusted
N_2O emissions from burning of field residues in croplands[a]	Global, all crops	0.07 g/kg dry matter combusted

Source: a, IPCC-EFDB (2009).; b, IPCC Guidelines for National GHG Inventories, Chapter 11 (IPCC, 2006a).

Note: This table shows a selection of default emission factors (EFs), provided by IPCC, that are relevant to the agricultural phase of tropical food product carbon footprinting.

is commonly thought to be N_2O from fertilizer, which can vary by orders of magnitude depending on factors such as climate, soil, crop and fertilizer type.

The work involved in calculating more accurate and specific emission factors is complex and time-consuming and can be cost-prohibitive (IPCC, 2006b). This has been reported by many countries as the reason why the EFs used for national GHG reporting are often default IPCC values (e.g., see UNFCCC National GHG Inventories of Pakistan or Sierra Leone). As well as geographic disaggregation of EFs, a wider range of data still needs to be developed. As an example, emission factors for CO_2 release from soil due to agricultural operation or from LUC activities are not yet reported in the database. The IPCC report the importance of data being continually updated and added to this database from outside users, but at present such data appear to be minimal.

Other Emissions Data

Country-specific EFs and data were sought through a literature review. Where data gaps were found, a continentwide value was sought. A selection of developed and less developed countries was chosen at random to provide comparative insight into the availability of data (and, thus, likelihood of reliance on default values) for calculating carbon footprints. The findings of this review are presented in Table 3.2 and discussed below.

The data in Table 3.2 demonstrate the limited nature of the information and emission factors that are available for carbon footprinting operations that occur in LDCs. Each category of emissions within food production faces subjective analysis if representative primary or secondary data are not available. For example, where an emission factor for road transport is not available, the default value which will be used in place may over- or under-estimate actual emissions. The results of making such data assumptions are presented in Chapter 5. The following sections discuss developing country data availability for each of the data categories listed in Table 3.2, drawing conclusions on how data deficiencies may impact developing countries.

Electricity Mix

Information about the electricity mix of most countries is readily available from the Energy Information Administration (2006), where generation is broken down into the following categories: conventional thermal, hydroelectric, nuclear, and renewable (geothermal, solar, wind, wood, and waste). The category of "conventional thermal" encompasses more than one type of electricity generation (e.g., gas, coal, oil); therefore, an average CO_2 emission factor would need to be assigned here, increasing the inaccuracy of this field. Disaggregated information may possibly be sourced through extensive literature review, but this can be time-consuming, and the accuracy of any information found would need to be verified. While a country-specific emission factor for electricity is assumed to be the best data option, this does not take into account seasonal variations in electricity supply, such as reduced hydropower during dry seasons, when diesel generators may be used during blackout periods.

Electricity Emission Factor

PAS 2050 guidelines state that a country-average emission factor for electricity should be used, although no reference is given to a source for this information. The GHG Protocol has listed a "grams CO_2/kilowatt hour" figure for the emissions generated from electricity for most countries, dating from 1990 to 2005. Data disaggregated by source (into electricity emissions from each of coal, oil, and gas) are also available. The GHG Protocol resources obtained for this study, however, show identical grams CO_2/kilowatt hour figures for coal- and oil-powered generation, suggesting a possible data error or an average value for both being assigned. These data originate from the International Energy Agency (2007) data

Table 3.2: Availability and sources of published, country- or region-specific key carbon footprinting data for a random selection of countries.

	Variable & Data Source					
Country	**Electricity mix**	**Electricity emission factor**	**Land-use change emissions factor**	**Agro ecological zones (*for study*)**	**Transport emissions factor (truck & rail)**	**N_2O emissions following fertilizer application**
UK	EIA	GHG Protocol	PAS 2050	SAGE	NGHGI	Bouwman et al. (2002)[a]
Norway	EIA	GHG Protocol	NGHGI	SAGE	NGHGI	—
USA	EIA	GHG Protocol	PAS 2050	SAGE	NGHGI	NGHGI
Australia	EIA	GHG Protocol	NGHGI	SAGE	NGHGI	NGHGI
New Zealand	EIA	GHG Protocol	NGHGI	SAGE	NGHGI	NGHGI
China	EIA	GHG Protocol	—	SAGE	RFA	Bouwman et al. (2002)[a]
Mauritius	EIA	GHG Protocol (*Africa value*)	—	—	RFA (*Africa value*)	—
Ecuador	EIA	GHG Protocol	—	SAGE	RFA (*Latin America value*)	—
Kenya	EIA	GHG Protocol	—	SAGE	RFA (*Africa value*)	—
Azerbaijan	EIA	GHG Protocol	—	SAGE	RFA (*FSU value*)	—
El Salvador	EIA	GHG Protocol	—	SAGE	RFA (*Latin America value*)	—
Algeria	EIA	GHG Protocol	—	SAGE	RFA (*Africa value*)	—
Sierra Leone	EIA	GHG Protocol (Africa value)	—	SAGE	RFA (*Africa value*)	—
Pakistan	EIA	GHG Protocol	—	SAGE	RFA (*Other Asia value*)	Bouwman et al. (2002)[a]

Italics show region represented by data where a country-specific value was not found.

[a] Except for China, values are reported for two or more different crops; value for China is for rice only. EIA = Energy Information Administration. GHG Protocol = Greenhouse Gas Protocol (data from International Energy Agency Data Services). *PAS 2050:* figure is calculated and listed in PAS 2050 document, and is based on IPCC defaults. NGHGI = National GHG Inventory. RFA = UK Renewable Fuels Agency. SAGE = Centre of Sustainability and the Global Environment at the University of Wisconsin–Madison, http://www.sage.wisc.edu/iamdata/units.php. FSU = Former Soviet Union. Italics represent continentwide rather than country-specific data.

services. Importantly, these emission factors do not include emissions from the processes that provide inputs to the electricity generation processes (e.g., coal mining, pipeline infrastructure), and as such they do not represent the full life cycle emissions of electricity generation.

When considering data availability for less developed countries, a number of data gaps exist, as represented by the categories "Other Africa," "Other Latin America," and "Other Asia" within the GHG Protocol list. For example, Mauritius and Sierra Leone do not have country-specific values assigned; thus the "Other Africa" emission factor would be assumed. This would also encompass Burkina Faso, however, which has a different electricity mix from Sierra Leone (Sierra Leone uses 100 percent conventional thermal, whereas Burkina Faso uses 80 percent conventional thermal and 20 percent hydroelectric). Similarly, a generic figure is given for countries not listed under Central and South America and the Caribbean, which encompasses Belize, Guyana, Suriname, and French Guiana, as well as Puerto Rico and a number of the smaller and wealthier Caribbean islands. The electricity mixes (and therefore emission factors) of these countries are varied, with Suriname using 90 percent hydroelectric power, Belize using approximately 50:50 hydroelectric and conventional thermal power, and most wealthy Caribbean islands using 100 percent conventional thermal power. More detailed information is therefore needed here; but this research exercise has not found easily accessible information outside of the mentioned sources.

Land Use Change Emissions

Land use change, or the conversion of nonagricultural vegetation to grass and cropland, can be a major source of GHG emissions for many countries (IPCC, 2006a). The greatest increases in cropland area to provide food and fiber over the last two decades have occurred in Southeast Asia, parts of south Asia, the Great Lakes region of eastern Africa, and the Amazon Basin (IPCC, 2006a). An average of 12 million hectares per year of forest was destroyed the tropics in the same time period (IPCC, 2006a).

Because the conversion of land to cropland has the potential to release large amounts of GHGs, PAS 2050 requires that these emissions be included in the assessment of a product carbon footprint. The total emissions resulting from direct land use change have to be included in the carbon footprint of any product arising from land converted to cropland, where 5 percent of total emissions are included in the GHG emissions of the product for each year during the 20 years following land use change. The assessment of these emissions is only required for land use change occurring on or after January 1, 1990. This cutoff point was chosen somewhat arbitrarily after lengthy discussions between the stakeholders involved in the development of PAS 2050. This has been a major criticism of the methodology owing to the historical nature of agricultural production in many developed countries, compared with more recent land conversion (and much remaining intact habitat) in developing nations. A greater burden is thus likely to be placed on less developed countries that wish to intensify their agricultural economy (see Chapters 4 and 5 for more detail), compared with developed countries where much land has been under agriculture prior to 1990. The United Nations Food and Agricultural Organization (FAO) reports that developing nations currently have around 50 percent of their cultivatable land under cultivation, compared to 78 percent in developed countries (Fischer et al., 2001). It further notes that over 80 percent of potential global cultivatable land reserves are located in South America and Sub-Saharan Africa. In comparison, the UK Renewable Fuels Agency (RFA), from which PAS 2050 originates some of its LUC values (based on IPCC methodology), uses a baseline of November 30, 2005, to measure LUC impacts against. In places where it can be shown that the land use change occurred more than 20 years before the assessment, no emissions from land use change need to be included, because they are assumed to have occurred prior to the application of the PAS. As many of the world's cultivatable reserves are also conservation priorities, the inclusion of LUC emissions is important to discourage conversion of native habitat to agricultural cultivation. However, it is also important to bear in mind the economic consequences, as most of these areas are located in countries with developing economies.

PAS 2050 makes provisions for cases where the origin of agricultural products is unknown to the assessors. If an agricultural product's country of origin is known, but the former land use is not, then GHG emissions from land use change are calculated assuming the highest potential emissions arising from land use change in that country. Where the country of origin is not known, GHG emissions arising from land use change shall be the highest potential emissions from land use change for all countries. This means land use change emissions have to be assumed to be the same as for the conversion of forest land to annual cropland in Malaysia, which is the highest value currently listed in Annex E of PAS 2050 (together with Brazil). The requirement to include this worst-case scenario in GHG assessments in cases where no data exist on country of origin and previous land use is assumed to provide enough incentive to users of the PAS to make every effort to report the origin of agricultural products.

Emissions from indirect land use change (i.e., the conversion of nonagricultural land to agricultural land as a consequence of changes in agricultural practices elsewhere) are not included in the current (first) version of the PAS. For example, indirect land use change might result from displacement of food agriculture or pasture land to another area following introduction of biofuel crops. However, indirect land use change emissions might be included in future revisions of PAS 2050 if methods and data requirements can be further developed.

Data availability

The PAS 2050 document includes an annex with a table listing figures for CO_2e emissions resulting from land use change for 16 countries (Table E.1), some of which are shown in Table 3.2. Figures given are single values for the conversion of either forest or grassland vegetation to annual or perennial cropland in t CO_2e ha^{-1} $year^{-1}$, with no distinction between different forest or grassland types.

The figures given in the PAS 2050 annex have been calculated according to the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006a). For countries not listed in this annex, the PAS 2050 user is referred to the IPCC Guidelines to carry out these calculations themselves. The guidelines thus provide the mechanism to calculate emissions from land use change for any country. Detailed equations and tables with default figures are provided for various ecological and climatic zones, soil types, etc. However, the calculation of LUC emissions according to IPCC methods can mask large ranges of emissions, leading to the over- or underestimation of carbon footprints (see Chapter 5).

Data availability for IPCC Tier 1 calculations (i.e. the least country-specific methodology) is not a problem, as IPCC (2006a) supplies default emission factors and other values needed for the calculations. However, should an analyst wish to use more detailed, country-specific data, it seems that these may be less readily available for developing countries, which have limited financial resources for collection and electronic publication of, for example, land inventories. A number of industrialized countries (Annex 1 countries to the UNFCCC Convention) such as those shown in Table 3.2 have calculated their own country-specific emission factors for LUC due to their requirement for National GHG Inventory reporting under the UNFCCC. As this is not a requirement for non–Annex 1 (developing) countries, most have not calculated country-specific emission factors for LUC due to the time-consuming and costly nature of such calculations. Less developed countries are therefore more likely to be penalized by this emission category in carbon footprinting methods, as a lack of country-specific data will mean reliance on IPCC default values—which may overestimate actual emissions (see Chapter 5 for how this can affect the overall product footprint).

Agro-ecological Zones and Land Utilization Types

The FAO and the International Institute for Applied Systems Analysis (IIASA) have categorized global land cover into 154 zones of potential agricultural productivity, or Land Utilization Types (LUTs). These have then been combined with socioeconomic, management and input criteria to define a broad set of agro-ecological zones (AEZs), intended as a tool for planning sustainable agriculture development in-country (Fischer et al., 2001). While LUTs and AEZs are not featured in either PAS 2050 or LCA methodologies, they are considered here as a potential mechanism for assessing the impacts of LUC by assigning emission factors specific to each zone.

Data on AEZs are readily available from the Center for Sustainability and the Global Environment at the University of Wisconsin-Madison (SAGE, 2000) (Table 3.3), for most countries globally. If a set of emission factors was developed for each AEZ, footprint practitioners could apply this information to calculate LUC emissions quickly and consistently, which could reduce the uncertainty surrounding IPCC Tier 1 calculations as described above and in Chapter 5.

This approach is already being used by the Brazilian Ministry of Agriculture and Supply, which has recently developed a Sugarcane Agroecological Zoning tool for appropriate expansion of the industry; information on soil, climate, environmental reserves, geomorphological and topographical maps, current land use, and other information were combined to form a definitive list of AEZs (BNDES, 2008). In addition, the FAO have formed a definitive list of Regional AEZs (RAEZs) within developing countries, identifying 23 RAEZs across Sub-Saharan Africa, West Asia and North Africa, Asia and the Pacific, and Latin America and the Caribbean, classified according to climate, length of growing period, land resources, and various socio-economic factors. The data linked with these classification systems, such as current or previous land cover and soil type, may help to calculate emissions from LUC for carbon footprinting. However, in order for this to be

Table 3.3: Number of agro-ecological zones (AEZs) within a sample of countries

Country	Number of AEZs
Algeria	5
Australia	13
Azerbaijan	5
China	13
Ecuador	11
El Salvador	2
Kenya	6
Mauritius	n/a
New Zealand	7
Norway	4
Pakistan	9
Sierra Leone	2
UK	5
USA	10

Source: AEZs defined according to land suitability for cultivation by the Centre for Sustainability and the Global Environment at the University of Wisconsin-Madison, http://www.sage.wisc.edu/iamdata/units.php. No data was given for Mauritius.

possible, emission factors and default figures for variables such as biomass contained in preconversion vegetation would need to be determined.

Transport

Emissions from transport (both within and between sites) as well as the associated emissions from fuel transport (e.g., pipelines, road transport) form an important element of carbon footprints, especially for products exported over large distances. Within PAS 2050, no specific reference to emissions values per tonne-km is given. Most Annex 1 countries have developed country-specific emission factors for various transport modes (see Table 3.2 for some examples), as reporting their emissions from this category is mandatory under the UNFCCC. However, as is clear from Table 3.2, many non-Annex 1 countries do not have country-specific emissions factors readily available, and would have to rely on the use of default values for calculating emissions from this category. As an example of default values, the RFA has published fuel efficiencies according to transport mode and location. Modes of transport detailed are truck and rail, and locations are broken down into OECD North America, OECD Europe, OECD Pacific, Former Soviet Union, Eastern Europe, China, Other Asia, India, Middle East, Latin America, and Africa. As with any large-scale assumption, the opportunity for error exists; and a single value for truck transportation within Africa, for example, is likely to disadvantage some suppliers and advantage others. See Chapter 5 for more detailed reporting on the uncertainty associated with these emissions factors.

N_2O Emissions Following Fertilizer Application

Nitrous oxides (N_2O) are reported to be the largest source of GHG emissions in agricultural commodity carbon footprints (Williams et al., 2006). Their accurate calculation should therefore be a priority in food product footprinting. Currently, however, most calculations are based on the IPCC default values shown in Table 3.1, almost all of which are "global" values, that is, defaults for all crops across all areas of the globe. This data assumption adds a large amount of uncertainty to the footprint as N_2O emissions released from agricultural soils following nitrogen fertilizer application vary considerably according to a number of factors including soil organic carbon content, crop type and climate (Stehfest & Bouwman, 2006). At present, emission factors disaggregated by geographic location or climate for this category are not readily available for most countries globally, but those who have calculated country-specific emission factors (e.g., New Zealand, Australia, United States) tend to be Annex 1 countries.

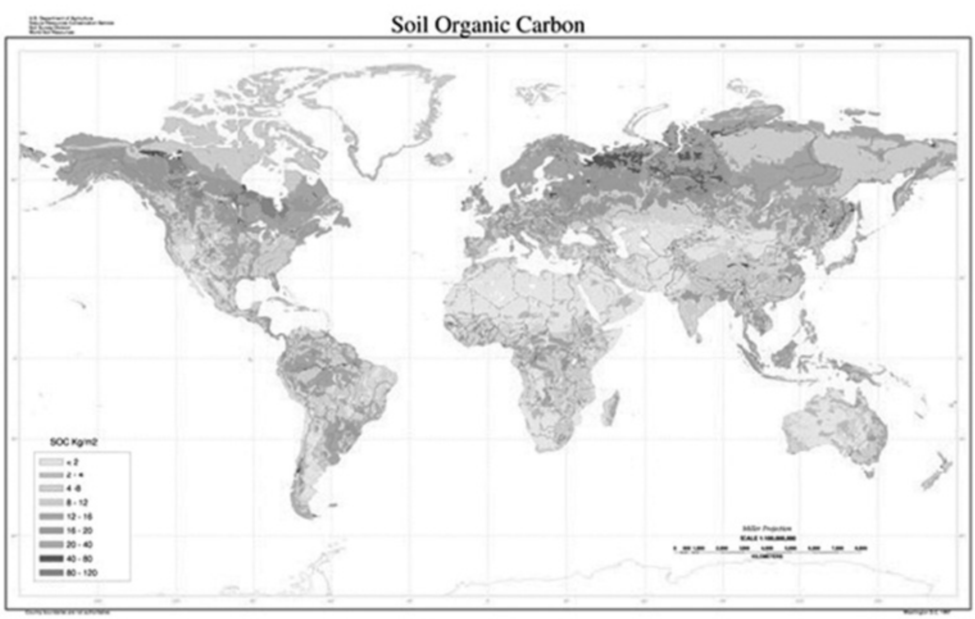
The default IPCC EFs have been criticized by many as over- or under-estimating the actual emissions from agricultural fertilizers. In reality, IPCC values currently provide the best global values as they are based on a sample of over 1200 measurements. However, it should remain a priority for countries with land-based economies to develop these data in order to ensure that producers are not penalized unfairly for this emission source.

Soil Carbon

Data on soil carbon are necessary to infer both potential release of carbon and potential carbon sinks through differing land management regimes.[1] This is of particular importance in the agricultural industry, where intensive annual production systems can result in a large release of carbon compared with, for example, low-tillage perennial crops.

The Harmonized World Soil Database, developed by the FAO and the IIASA, is a free, downloadable tool which enables the user to view global maps of soil properties such as organic carbon levels. However, although useful graphical maps can be produced, the accompanying metadata do not appear to be available to the user, therefore definite levels of soil carbon cannot be easily extracted from this tool. This is also true of a number of other sources of soil carbon maps, such as that of the US Department of Agriculture (USDA), presented in Figure 3.1. The Center for Sustainability and the Global Environment (SAGE,

Figure 3.1: Global soil organic carbon to 1m depth.



Source: From soils.usda.gov/use/worldsoils/mapindex/soc.html

University of Wisconsin-Madison) have a downloadable soil metadata resource, but this is only viewable in formats requiring specific software or translation (e.g., ASCII, NetCDF). It is important to note that in order to calculate GHG emissions from soils resulting from agricultural operations such as plowing, a locally or regionally specific emission factor would be needed.

IPCC-EFDB (2009) provide default values for the amount of soil carbon contained in a variety of soils (see Table 3.4) as well as equations that allow the calculation of annual changes in soil carbon stocks using default emission factors, stratified by climate region and default soil types. Stock changes calculated are broadly defined and include a land use factor that reflects soil carbon changes associated with the type of land use (e.g., annual crops), a management factor reflecting the principal management practice (e.g., full or reduced tillage), and an input factor representing returns of carbon to the soil. As with other Tier 1 calculations, results will not be very location-specific, but the calculation of these soil carbon changes using higher Tier approaches is expected to be unrealistic for carbon footprint calculations due to time and resource constraints. Currently, PAS 2050 and other carbon footprinting methods do not include changes in soil carbon.

Conclusions

There publicly accessible resources present some of the data required to calculate the carbon footprints of agricultural products. However, much of the available data is applicable to industrialized countries in Europe, North America, and Australasia. Where data are available for LDCs, they tend to be relevant to very large regions—and can be surrounded by considerable uncertainty. In many ways this situation reflects the degree of scientific

Table 3.4: Carbon quantities for soil in various tropical conditions

Regional Conditions	Soil carbon (tonnes C ha^{-1})
Tropical, dry; high-activity soils	60
Tropical, dry; low-activity soils	40
Tropical, dry; sandy soils	4
Tropical, dry; volcanic soils	50
Tropical, dry; Wetland soils	60
Tropical, moist (long, dry season); high-activity soils	100
Tropical, moist (long, dry season); low-activity soils	50
Tropical, moist (long, dry season); sandy soils	5
Tropical, moist (long, dry season); volcanic soils	70
Tropical, moist (long, dry season); Wetland soils	100

Source: IPCC-EFDB (2009).

Note: This table lists the approximate quantities of soil organic carbon under native tropical dry and moist vegetation (0–30 cm depth).

endeavor that has been ongoing around the globe over the last 30 to 40 years, which has tended to focus on developed countries.

The absence of good-quality, location-specific data presents a real challenge to those analysts who try to construct carbon footprints for food products grown in tropical countries. Because of the nature of the available data, these analysts will be forced to use the best available data for a region without really knowing how valid these data are to the case being analyzed. Even if there are one or two scientific studies available for certain countries, it is unclear how widely applicable these data are—and whether or not they can adequately describe the situation across the whole country. The issue of the representativeness of available data to developing countries is perhaps of more importance than it is in many European situations, as many developing countries are larger than most European countries and also contain highly varied ecosystems, microclimate, and agricultural practices. One way to approach the development of suitable emission factors and data for use in developing countries would be to create data sets that are relevant across agro-environmental zones. This would enable some sharing of data between countries and would also enable natural variation within countries to be represented in a relatively simple and understandable form.

Note

[1] At present, PAS 2050 excludes soil carbon from its methodology, but is being considered for future revisions. According to ISO guidelines, LCA practitioners may choose whether or not to include soil carbon sources and sinks in their calculations.

CHAPTER 4

Case Study: Carbon Footprints of Tropical Food Products Calculated According to PAS 2050

Summary

Carbon footprints were calculated for four products according to the methodology specified in PAS 2050: sugar from Zambia, sugar from Mauritius, and fresh pineapples and pineapple jam from Mauritius. Emissions from land use change had the largest impact on the carbon footprint of sugar from Zambia. However, because agricultural fields on Mauritius had been cleared of native vegetation prior to 1990, these emissions were not included in the carbon footprint. The carbon footprint of fresh pineapple was dominated by emissions related to the air freight to Europe. In contrast, pineapple jam had relatively low emissions from transport, as it was shipped to Europe. Chapter 5 will present a sensitivity analysis of key emission categories that might vary between different carbon accounting methodologies using the case studies presented here.

Introduction

This chapter presents the carbon footprint according to PAS 2050 for four case studies: sugar from Zambia, sugar from Mauritius, and fresh pineapples and pineapple jam from Mauritius. It is organized into four sections: the methods section describes the sites visited, data collection, and how the data were analyzed; the results section presents the carbon footprint for the case study products up to their arrival in Europe; and the discussion section considers differences between farms and case studies, problems in applying the PAS methodology, as well as gaps in data availability and the methodological approach. The case studies also highlight the advantages of processing within the developing country as compared to the export of fresh air-freighted produce in terms of the product's carbon footprint.

Methods

PAS 2050 Methodology

PAS 2050 is built upon the existing ISO 14040/44 standards for LCA. These ISO standards are further clarified and specified in PAS 2050, which establishes additional principles and techniques that address essential aspects of carbon footprinting. A PAS-compliant carbon footprint can be calculated either as a business-to-consumer assessment, which includes the full life cycle of a product ("cradle to grave"); or as a business-to-business assessment, which includes all upstream GHG emissions up to the arrival of a product as an input to a new business or organization ("cradle to gate"). PAS 2050 accounts for emissions of all GHGs including CO_2, N_2O, CH_4, and families of gases such as hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). Each gas is converted into a CO_2 equivalent value, determined by its ability to trap heat in the atmosphere over a 100-year period relative to CO_2, known also as its global warming potential (GWP).

PAS 2050 specifies rules for identifying the system boundary and data quality rules for secondary data. GHG emissions from energy use, combustion processes, chemical reactions, refrigerant losses and other fugitive gases, operations, service provision and delivery, land use change, livestock, other agricultural processes, and waste have to be included in the assessment. The unit of analysis should be the unit in which the product is actually consumed by the end user. Direct land use change emissions where the land use change occurred on or after January 1, 1990, should be calculated according to the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006a). One-twentieth (5 percent) of the total emissions arising from the land use change have to be included in the GHG emissions of the products concerned in each year over the 20 years following the change in land use. Non-CO_2 emissions from livestock, their manure, and soils are to be calculated in accordance with the highest tier approach set out in IPCC guidelines or the highest tier approach employed by the country in which the emissions arise. Any changes in the carbon content of soils are excluded (either emissions or sequestration) other than those from direct land use change due to the considerable uncertainty in their assessment. Capital goods are also not included in the PAS 2050 methodology, although this category might be of significance for agricultural products, where agricultural machinery has been shown to have an impact (Weidema et al., 1995). In addition, PAS 2050 makes provisions for carbon storage in products and delayed emissions from the use phase and final disposal of a product; however, these did not apply to the case studies presented here. Emissions related to human energy inputs, transport of consumers to and from shops, transport of employees to and from work, and animals providing transport services are excluded from the carbon footprint calculation.

Data Collection

Primary data for the case studies were collected by visiting farms and processors in Zambia and Mauritius. Data collection in Zambia took place between March 30 and April 9, 2009, and in Mauritius from April 19 to May 9, 2009, and was carried out via questionnaire-style interviews with farm owners, agricultural managers, factory managers, financial controllers, and wider industry contacts.

Description of Sites

The carbon footprint of products can be commercial sensitive. In order to protect the businesses that participated in the project, we are only providing very limited information on the farms, refineries, and factories that were visited. This will prevent their identity from becoming known to industry experts and thereby protect their confidentiality. As a result of participating in the project, all businesses receive an individual report detailing their carbon footprints, and it is up to them to use this as they see fit in the future. The farms are expected to be representative of the production systems in both countries; however, due to the small sample size, the results should not be interpreted to be statistically representative of those two countries. The variation in carbon footprints can be large between farms within the same country—and sometimes can be larger between individual farms than between different countries of production for the same product (Edwards-Jones et al., 2009). In the presentation of the results and the discussion, the sugar estates in Zambia are labeled Farm A, B and C; Farm D is the sugar estate visited in Mauritius. Refinery A is in Zambia, Refinery B in Mauritius. Both pineapple case studies were based in Mauritius.

Sugar in Zambia

Three sugar cane estates (Farm A, B, C) and one refinery (Refinery A) were visited in the sugar-growing district of Zambia. The farms varied greatly in size and annual yields.

The sugar industry in Zambia is currently entering a large expansion program, with the dominant player in the industry reporting almost a 50 percent increase in production year-on-year. This rapid expansion has led to the conversion of much natural, previously uncultivated land to agriculture. Sugar grown in Zambia supplies virtually all of the domestic market, and is exported to the European Union and the United States.

Annual farm yields were found to vary significantly between farms, ranging from 70 to 150 tons cane per ha. Irrigation methods were similar on all three sites, dominated by center pivot systems rotating around circular plots. In addition, some farms contained small areas of canal and sprinkler irrigation. All three farms have converted some or all of their cultivated land from native "bush" vegetation since 1990, which means emissions from land use change had to be included in a PAS 2050 compliant carbon footprint. Furthermore, two farms reported their plans to expand cane cultivation in the near-term, in line with planned expansion of the sugar industry in Zambia. The main inputs to all three farms were fertilizers, applied at least twice per year, but the production origins of fertilizers were not known. No pesticides were reported to have been used on any of the case study farms. Over half of on-farm operations (planting, fertilizer application, and harvest) were carried out manually.

On all three farms, harvesting cane begins with field burning in order to remove excess vegetation and snakes, as most cutting is carried out by hand. Extracted raw sugar yields vary year-to-year according to the percentage sucrose content of cane, averaging around 12 percent of cane weight.

The refinery operation visited (Refinery A) was powered by renewable energy in the form of bagasse (the fibrous sugar cane residue), making this a highly energy self-sufficient processing system. At the time of data collection, Refinery A was not exporting outside of Africa, thus export data were collected from suppliers of a nearby refinery. The output from Refinery A is raw sugar.

Sugar on Mauritius

Farm D is a long-established sugar estate where conversion of the land to cropland occurred over 100 years ago. The growing cycle consists of 6–7 ratoon years. About 65 percent of the area under sugar cane is irrigated using drip irrigation and pivot systems. During the ratoon years, a CMS (Condensed Molasses Solubles) fertilizer is applied; this is made from vinasse, a byproduct from distilleries, which is naturally rich in potassium. No ripeners or pesticides are used. At harvest, cane leaves are left on the soil surface, and no burning is practiced. Manual labor is employed for planting and the application of base dress fertilizer.

The rocky soils on Mauritius make mechanical harvesting impossible. Increasingly, de-rocking operations are carried out in order to remove large rocks and level the land, allowing mechanical harvesting. These operations remove large amounts of stones and use big machinery. Large-scale de-rocking was undertaken on parts of Farm D more than 10 years ago, and fine de-rocking is carried out manually with workers picking up loose surface stones after planting every 6–7 years.

Refinery B uses bagasse as an energy source for the sugar processing, but it also exports energy generated from excess bagasse to the national electricity grid, making bagasse an important byproduct to the sugar processing. Another byproduct from this refinery is molasses, which is then used as an input by rum distilleries. Sugar recovered amounts up to 10 percent of the cane. Data collected from Refinery B include all processes up to the production of white sugar ready for consumption and thus are not directly comparable with Refinery A, which produces raw sugar.

Pineapples on Mauritius

This farm exports over 50 percent of its pineapples (variety Queen Victoria) to Europe. Most of the work on the farm is done manually, including harvesting, planting, and the application of fertilizers and plant hormones. Soil preparation is done using small machines in most years, but deep plowing using a caterpillar becomes necessary every few years. Harvested pineapples are transported to the airport to be air-freighted to their markets in Europe. The average weight of export-quality fruits was 500 g.

The land used to be part of a sugar estate that was established long before 1990, so no emissions related to land use change need to be included in the assessment of the PAS 2050-compliant carbon footprint.

Pineapple jam was chosen as a case study as a comparator to the production of fresh pineapple. The sugar used in the jam is sourced from Thailand, because almost all local sugar is currently exported.

Data Analysis

The carbon footprint for all case studies was calculated according to PAS 2050. The analysis does not cover the whole life cycle of the product, but includes all emissions from cultivation, processing, and transport to European export destinations, and as such represents a business-to-business assessment. Primary data collected from the farms and refineries was used as much as possible. Emission factors were extracted from the Ecoinvent database (Althaus et al., 2007; Nemecek et al., 2007; Spielmann et al., 2007), Carbon Trust (2008) and the International Energy Agency (2007). Direct emissions from land use change (i.e., the conversion of nonagricultural to agricultural land) were calculated according to IPCC (2006a) as required by PAS 2050 for products that arise from land that was converted to agricultural land since 1990. This applied only to Farms A, B, and C, whereas no land use change after 1990 had occurred on Farm D and the pineapple farm.

Emissions from diesel use for the conversion of native vegetation to cropland were included in the calculations for Farms A through C and allocated over a 100-year time period. Diesel usage for de-rocking as carried out on parts of Farm D 10 years ago was also included and, again, allocated over 100 years.

The sugar industry can have multiple outputs: sugar; export of electricity to the national grid produced from excess bagasse; and molasses, which is an input to alcohol distilleries. GHG emissions were allocated between these three outputs using economic allocation in accordance with PAS 2050. This allocation between outputs was only relevant to Refinery B, because no export of excess electricity from bagasse to the national grid occurred in Refinery A, and molasses was treated as waste. This means that for Refinery A, all GHG emissions from the cultivation and refining of the sugar were allocated to the raw sugar at the refinery gate. In contrast, only 91.7 percent of GHG emissions were allocated to the sugar leaving Refinery B, 5.7 percent to the bagasse, and 1.6 percent to the molasses.

Because Refinery A was not exporting outside of Africa, export data were collected from suppliers of a nearby refinery. From this refinery, about 90 percent of the raw sugar is transported by road or rail to Durban (South Africa) at a distance of 2200 km. The remaining 10 percent are trucked to Beira (Mozambique, 2000 km). Based on these distances and modes of transport, GHG emissions from this transport stage were calculated. Refinery B is located an undisclosed distance from the port in Mauritius, and sugar is transported there by truck. Sugars produced in both case study countries are shipped to their markets, which are mainly in Europe and the United States. Results presented here are for sugar delivered to a destination port in Europe.

No allocation of emissions between pineapples of export quality and non-export quality was made; however, the latter are sold on local markets and could be regarded as a byproduct. Transport to the airport was nonrefrigerated.

Calculation of Land Use Change Emissions for the Case Studies

The estimation of emissions resulting from the conversion of nonagricultural land to cropland according to the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006a) involves estimates of annual changes in carbon stocks for above-ground biomass, dead organic matter (dead wood and litter), and soil organic matter. Due to very limited data availability on below-ground biomass stocks in perennial cropland, these are not included in the calculations.

For the case studies analyzed here, emissions resulting from land use change were only relevant for sugar cane production in Zambia. Although sugar cane is a perennial plant, calculations for land use change emissions in Zambia were carried out as if it was an annual plant. This decision was made because all above-ground biomass is removed yearly during harvest, and although the amount of root biomass will increase during the 5–7 year cycle, this increase in below-ground carbon stocks is not included in the IPCC methodology due to lack of data.

Calculations were made according to IPCC Tier 1 methods and mainly using Tier 1 equations, assumptions, and default values (IPCC, 2006a). Tiers 2 and 3, as defined by IPCC, are more country-specific methods; however, it was outside of the scope of this study to attempt a Tier 2 calculation, while Tier 3 calculations usually are only made by the countries themselves when reporting on countrywide GHG emissions following IPCC guidelines. However, the use of the simplest Tier 1 with the least country-specific emission factors is expected to accurately reflect the approach applied by most users of PAS 2050.

Results

Sugar

Carbon footprint for sugar cane delivered to the refinery

Total GHG emissions for the cultivation of sugar cane up to the point of delivery to the refinery varied between 26 and 210 kg CO_2e per t sugar cane (Table 4.1). The table also shows the percentage contribution for each of the inputs and processes on the farms. Land use change emissions, which are relevant to Farms A through C only, have by far the largest share in the carbon footprint (66–77 percent). Farm D, on the other hand, has not converted any land since 1990, so no land use change related emissions had to be included. Other reasons for interfarm variation are differences in farming practices (e.g., the amount of fertilizers applied), intensity of irrigation, and associated use of electricity, as well as average yields per hectare. Emissions related to the use of electricity are very low for Farms A through C due to the national electricity mix being based largely on renewable hydroelectricity.

Carbon footprint for sugar at the import gate

The major input in terms of GHG emissions for both refineries was the sugar cane (Table 4.2). All other inputs, such as diesel and chemicals, together accounted for less than 5 percent of GHG emissions at the refinery gate. The total carbon footprint for raw sugar leaving Refinery A and white refined sugar from Refinery B was 1731 kg CO_2e/t sugar and 255 kg CO_2e/t sugar, respectively (Table 4.3).

Transportation by rail and truck to ports for shipping to Europe added 201 and 5.4 kg CO_2e per ton of sugar from Refinery A and B, respectively. Overseas shipping to Europe had a similar impact for both case study countries, amounting to 130 kg CO_2e per t for sugar from Refinery A and 138 kg CO_2e per t of sugar for Refinery B. Overall, these transportation steps added 331 and 143 for Refinery A and B, respectively (Table 4.3), bringing the total carbon footprint to 2100 kg CO_2e per t raw sugar for Refinery A and 400 kg CO_2e per t of white sugar for Refinery B at delivery in Europe.

Table 4.1: GHG emissions per ton of sugar cane

Farm Name		Farm A	Farm B	Farm C	Farm D
Emissions from the production of inputs					
Diesel usage	%	2.8	3.0	7.2	19.7
Electricity from national grid	%	0.1	0.2	0.3	23.8
N	%	8.8	8.4	10.8	19.6
P_2O_5	%	1.0	1.2	1.4	0.0
K_2O	%	2.0	0.8	1.9	4.2
S	%	0.0	0.1	0.1	0.0
Fe	%	0.02	0.01	0.03	0.0
B	%	0.1	0.1	0.1	0.0
Zn	%	0.0	0.1	0.1	0.0
Cu	%	0.0	0.01	0.0	0.0
Mn	%	0.0	0.3	0.0	0.0
Lime	%	0.0	0.0	0.009	0.0
Pesticides	%	0.0	0.0	0.7	0.0
Emissions from ecosystem processes					
Land use change emissions	%	76.2	77.4	66.1	0.0
N_2O from N fertilizer	%	8.9	8.5	10.9	32.8
CO_2 from lime application	%	0.0	0.0	0.3	0.0
Total kg CO_2e/t sugar cane		**210**	**92**	**64**	**26**

Note: This table shows the percentage of GHG emissions per ton of sugar cane for four sugar cane estates, from the manufacture of inputs and ecosystem emissions up to the delivery of the sugar cane to the refinery. Also shown is the total carbon footprint in kg CO_2e/t sugar cane, including rounding of the final figure to two significant figures as required by PAS 2050.

Table 4.2: GHG emissions per ton of raw sugar

	Refinery A	Refinery B
Sugar cane	99.99	95.88
Grid electricity	0.0	0.10
Diesel usage	0.0	0.01
Water	0.0	0.68
Lime	0.01	0.03
Other flocculants/coagulants	0.0	0.01
Other flocculants/coagulants	0.0	0.003
Caustic soda	0.002	0.64
Phosphoric acid	0.0	0.74
Cationic colour precipitant	0.0	1.16
Sodium chloride	0.0	0.59
Sulphur	0.0	0.17

Note: This table shows the percentage of GHG emissions per ton of raw sugar (Refinery A) and white sugar (Refinery B) for each input and total carbon footprint in kg CO_2e/t sugar (including economic allocation between outputs).

Table 4.3: The carbon footprint of sugar in transit

	Refinery A	Refinery B
Total kg CO_2e/t sugar at refinery gate	1731	255
In-country land transport (inc. to port)	201	5.4
Transport to Europe	130	138
Total kg CO_2e/t sugar at import port	**2100**	**400**

Note: This table shows the carbon footprint in kg CO_2e/t sugar (including economic allocation between outputs) at the refinery gate, for transportation steps to port and from shipping to Europe, and total carbon footprint for sugar at the import gate in Europe for raw sugar (Refinery A) and white sugar (Refinery B), including rounding of the final figure to two significant figures as required by PAS 2050.

Fresh Pineapples

The carbon footprint of pineapples delivered to the airport to be air-freighted to their markets in Europe was 0.23 kg CO_2e per kg of pineapples. Table 4.4 shows the contribution of the various inputs and processes to the carbon footprint. The use of diesel on the farm had the greatest impact on the carbon footprint at the farm gate (26 percent), followed by the manufacture of N:P:K fertilizer (24 percent) and urea (15 percent) as well as nitrous oxide emissions following nitrogen applications to soil (16 percent).

Trucking of pineapples to the airport amounts to 0.02 kg CO_2e per kg of pineapples. Transportation by air to Europe (10,000 km) adds another 10.8 kg CO_2e per kg of pineapples, highlighting the great impact that this mode of transportation over large distances can have, bringing the total carbon footprint up to delivery in Europe to 11 kg CO_2e per kg of pineapples.

Pineapple Jam

The main inputs in terms of GHG emissions during the production of pineapple jam were the glass jars, diesel, lids, and fresh pineapples (Table 4.5). The total carbon footprint was 1.2 kg CO_2e/kg of jam at the factory gate. Transportation by truck to port added a negligible

Table 4.4: GHG emissions for fresh pineapple

Inputs and processes		
Diesel usage	%	26.2
Electricity usage	%	2.8
Plastic production (for mulching)	%	6.9
TSP fertilizer production	%	4.8
Urea production	%	15.1
Potassium sulphate production	%	1.4
N:P:K fertilizer (17:8:25)	%	23.9
Herbicide production	%	1.8
Ripener production	%	0.6
N_2O from N fertilizer	%	16.4
Total kg CO_2e/kg of pineapple		**0.23**

Note: This table shows the percentage of GHG emissions per kg of fresh pineapples produced on a single farm delivered to the airport. Also shown is the total carbon footprint in kg CO_2e/kg fresh fruit.

Table 4.5: GHG emissions for pineapple jam

Inputs		
Total electricity		1.5
Total diesel usage	%	13.2
Pineapples	%	12.2
Sugar	%	8.5
Pectin	%	0.4
Lemon juice	%	0.0002
Jars	%	42.6
Lids	%	12.8
Total ingredients transport to factory	%	8.7
Total kg CO_2e/kg of jam		**1.2**

Note: This table shows the percentage of GHG emissions per kg of pineapple jam delivered to port. Also shown is the total carbon footprint in kg CO_2e/kg jam.

amount and shipping to Europe added 0.138 kg CO_2e/kg of jam, increasing the total carbon footprint to 1.3 kg CO_2e/kg of jam at the import port.

Discussion

The Carbon Footprint of Sugar Produced in Zambia and Mauritius

The carbon footprint calculated according to PAS 2050 ranged from 0.03 to 0.2 kg CO_2e per kg of sugar cane at delivery to the refinery. This shows that GHG emissions from the farming stage can vary greatly between different estates. The most important issue for Farms A through C were the emissions from land use change, which dwarf every other input and process on the farms in terms of GHG emissions. For Farms A and B, land use change emissions were relevant for the total farm area, whereas Farm C had only converted 60 percent of its area since 1990. This, coupled with high yields, led to a lower carbon footprint for Farm C than Farms A and B. If land use change emissions were not included for Farms A through C, then Farms B, C and D would have similar carbon footprints per kg of sugar cane. The comparison between farms with and without land use change since 1990 presented here highlights two issues: where forest land is converted to cropland in tropical countries, emissions from land use change are likely to be very large and dwarf emissions from cultivation practices; and tropical countries or individual farms that are expanding their agricultural area will have much higher carbon footprints for their agricultural products calculated in accordance with PAS 2050 than countries or farms that do no convert native vegetation.

Mitigation measures applied on Farms A to C (e.g., the reduction of mineral nitrogen fertilizer) will not lead to a significant reduction in the carbon footprint for the 20 years that PAS 2050 requires land use change emissions to be included in the assessment. Farm D, on the other hand, might be able to reduce its carbon footprint even further by measures such as a reduction of fertilizer inputs and use of renewable energy sources or sugar cane varieties with increased yields that do not require increased inputs.

The assessment of the impact of mechanization on the carbon footprint is difficult because we do not know the exact number of person days involved in the manual operations on all four sugar estates; the only indicator we have for this is the amount of diesel used per ton of sugar cane produced. This was similar for all farms, although Farms A through

C should have higher levels of manual labor than Farm D. No firm conclusions can thus be drawn on this issue from the four case studies. The production and maintenance of farm machinery was not included in the analysis in accordance with PAS 2050.

Due to the difference in the carbon footprint of sugar cane in both countries, sugar at the refinery gate had an almost 7 times greater carbon footprint for Zambia than Mauritius. The refining process does not add a great amount of GHG emissions, mainly because both Refinery A and B are mostly self-sufficient in use of energy, which is generated from the burning of bagasse. As Refinery B also exports electricity to the national grid and molasses is an economic byproduct, the carbon footprint per unit of sugar is reduced by a proportion of the revenue gained through economic allocation. Ongoing initiatives and research on Mauritius might lead to an increase in the amount of electricity exported to the grid, potentially further reducing the carbon footprint in the future.

A different way of allocating GHG emissions between byproducts would be to calculate the amount of emissions avoided by displacing another product. In the case of electricity production from bagasse on Mauritius, this would mean a displacement of electricity generated mainly from coal and oil, leading to avoided emissions from using these fossil fuels. Avoided emissions from the export of electricity to the national grid on Mauritius amount to 360 GWh per year, equivalent to 306,327 t CO_2, or around 65 kWh per ton of cane (Ramjeawon, 2004). If these avoided emissions were included in the carbon footprint of sugar from Refinery B, the result would be very different from the figures presented above using economic allocation; a preliminary analysis indicated that the avoided emissions would far outweigh those from cane cultivation and processing. Accounting for avoided emissions would not be relevant to Zambia where the sugar industry does not export electricity to the grid; and if it did, these would be minimal due to the very low national electricity emission factor based mainly on hydropower.

The greater distance of the Zambian sugar estates to ports means that transport emissions prior to shipping are much greater than for a small island such as Mauritius; this factor will have an impact for any landlocked country located far from ports (Edwards-Jones et al., 2009), although shipping will still be more advantageous in terms of GHG emissions than air-freighting.

Comparison with other studies

In a study conducted by Myclimate for the Swiss supermarket chain Migros (see Chapter 2), GHG emissions were estimated for six different sugars using standard LCA methods: sugar cubes, granulated sugar, and organic granulated sugar from sugar beet produced in Switzerland and Germany; sugar cubes and raw sugar made from sugar cane produced in Columbia; and organic cane sugar from Paraguay. Out of these six products, sugar from sugar beet had the highest carbon footprint, while the organic sugar cane product from Paraguay had the lowest carbon footprint (around 0.34 kg CO_2e/kg sugar). This analysis did not include any land use change emissions, because no land use change had occurred recently on the farms in Paraguay. Overseas shipping from Paraguay to Switzerland had the largest share in the carbon footprint, followed by GHG emissions during cultivation. For sugar from Switzerland, the cultivation of the sugar beet had by far the largest share in total GHG emissions, followed by processing. The impacts of packaging and waste disposal were found to be insignificant. Emissions from retailing were not considered due to a lack of data and because its share in total emissions is expected to be very insignificant once allocated over the large amounts of products sold. Consumer travel was not included. The results of the present case study where land use change was not an issue (0.4 kg CO_2e/kg refined sugar delivered to Europe) are comparable to sugar from Paraguay, and the inclusion of emissions from packaging and disposal would not increase the carbon footprint by a large amount. No other studies were identified that analyzed GHG emissions from cane sugar including land use change emissions. In the present study, the carbon footprint of the case study including land use change was more than 5 times greater than the case study where no land conversion has occurred for many decades.

British Sugar has determined the carbon footprint of sugar produced in the United Kingdom from sugar beet using the PAS 2050 methodology as 0.6 kg CO_2e/kg sugar up to the delivery of the product to food and drink manufacturers (www.britishsugar.co.uk). A German modeling study, looking at all life-cycle stages from cultivation to retailing, estimates the carbon footprint of beet sugar at 1.46 kg CO_2e/kg sugar (Stratmann et al., 2008).

The results of our case studies and other calculations described above highlight the fact that commodities produced at large distances from their markets can have a lower climate change impact than alternatives produced in Europe.

Pineapples: Fresh vs. Processed Products

At the farm gate, emissions from the cultivation of pineapples are very low and compare well with other fruit; for example, GHG emissions from oranges produced in Spain have been estimated at 0.25 kg CO_2e/kg at the farm gate (Sanjuán et al., 2005, cited in Garnett 2006). However, because pineapples in this case study are air-freighted to their European destination due to their short shelf life, their final carbon footprint increases to 11 kg CO_2e/kg. Fruit that can be shipped, in contrast, can have a much lower carbon footprint, such as kiwi from New Zealand (0.75 kg CO_2e/kg up to European retail stores) or oranges and grapefruit from South Africa (0.92 kg CO_2e/kg up to European retail stores) (Soil & More, 2008a, b). The carbon footprint of fresh pineapples is similar to that of other fresh produce that is air-freighted from Africa, for example, green beans (11 CO_2e/kg up to consumption) (Milà i Canals et al., 2008). The production of highly perishable fruit and vegetables in heated and lighted glasshouses in European countries can have similar carbon footprints to tropical produce that is air-freighted to Europe—for example, conventional and organic U.K. glasshouse tomatoes have a carbon footprint of 9.1 and 17.5 kg CO_2e/kg, respectively, at the farm gate (Williams et al., 2006), although other authors have calculated lower figures. Other produce with large energy consumption during protected cultivation, leading to a high carbon footprint, include peppers and cucumbers (Jones, 2006).

If the shelf life of a product can be extended through processing, making it possible to transport that product to its final market by ship instead by air, then GHG emissions can be reduced by large amounts. This was shown in the pineapple jam case study, where processing of fresh pineapples into jam, which then is transported by ship, resulted in a much lower carbon footprint of 1.3 kg CO_2e/kg jam. Because of this, it may be advantageous to encourage processing in the country of production, which would also add value, increase revenue, and thus lead to other socioeconomic benefits for the producing country.

Problems in Applying PAS 2050

Data gaps and assumptions made

Despite extensive data collection during site visits, discussions with industry representatives, and further follow-up discussions with farmers, processors, and other contacts made during the data collection visits, some data gaps still remained; and assumptions had to be made to calculate the carbon footprints. In general, the sugar industry on Mauritius is in a good position to calculate carbon footprints because it is highly organized and a lot of data is collected annually by the various sugar organizations, whereas less detailed and reliably documented information was readily available in Zambia, and the data collected on inputs used was very likely incomplete. This kind of problem can have an impact on the final result because, generally speaking, the more information on processes and inputs is available, the more emissions can be included and the higher the carbon footprint will be. This means that the more time is spent on collecting and analyzing data, the more accurate the result will become, but also the final figure is likely to be greater than if less time and effort was invested. This situation might inadvertently penalize those businesses that produce the most accurate carbon footprints in a competitive situation; the advantage is that these businesses will also have the greatest opportunity to identify emissions reductions.

On the sugar estates, one potentially important data gap was the lack of information on the amount of organic fertilizers applied to the sugar cane fields. Although it is known that the scum, which is an output from sugar processing, is used by many farmers as a fertilizer that goes back onto their fields, we do not know the amounts involved or its composition and organic nitrogen content. This means that we could not account for N_2O emissions resulting from this nitrogen input. Farm D applies a fertilizer called CMS (Condensed Molasses Solubles), which is based on molasses or vinasses. It is naturally rich in potassium and probably contains a large percentage of organic matter. Nitrogen and possibly phosphorus are added during the production of the fertilizer from the vinasse. We could not get any information on the amounts applied to Farm D by the contractor carrying out these operations and had to base our calculations on assumptions. Another problem relates to the calculation of GHG emissions from the manufacture of this product, which we probably have overestimated by accounting for the production of the potassium even though it is naturally present in the CMS fertilizer. The calculations of diesel usage for Farm D are very accurate and based on detailed information given to us by the contractor, who does all land preparation for planting, ridging up after planting, and harvesting operations on this farm. This contrasts with Farms A through C, where the primary data obtained was less detailed, so more assumptions on size of machinery and diesel usage per hour and per hectare, and so on, had to be made.

There is some uncertainty about the amount of electricity used during the jam processing, and the total weight of fresh pineapples before the cooking process was unknown to us. No emissions from the production and printing of the labels on the jars of jam are included due to lack of immediate data and negligible impact. No recycled content of glass or metal for lids was included.

Lack of country-specific emission factors

Extensive research confirmed the lack of country-specific emission factors for many inputs and processes for both Zambia and Mauritius. This necessitated the use of emission factors from databases such as Ecoinvent, which were derived mostly for European systems and will not accurately reflect the situation in the case study countries. The lack of country-specific emission factors was confirmed by two LCA practitioners on Mauritius who have had to use the European/OECD country emission factors for their own work. Although it is unknown whether this leads to an under- or overestimation of the resulting emissions, this issue is a significant problem for those working in the field. It is especially important that GHG emissions and product carbon footprints are estimated as accurately as possible because of the commercial advantages or disadvantages that might result from a low or high carbon footprint. Because this lack of emission factors has been identified as a problem, one group at the University of Mauritius is currently working on developing an emission factor for electricity, and they would also like to see a national database developed. The electricity emission factor used for Mauritius in this study was calculated according to CDM guidelines (according to S. Deenapanray, National Project Coordinator Clean Development Mechanism, Mauritius) which appear to differ from the calculation of emission factors contained in databases such as Ecoinvent. This emission factor is unusually high and, as such, represents a worst-case scenario approach.

Problems in modeling complex systems

As all sugar produced on Mauritius is sold and marketed as one entity, rather than each estate making its own arrangements, the system of sharing revenues between planters, millers, and refiners is a complex one. This is further complicated by the fact that there are several economic outputs (sugar, bagasse, molasses). This could represent a problem when trying to calculate a carbon footprint without the time and resources to either visit the country or do in-depth research on the structure of the industry. For example, a detailed knowledge of industry structure was essential to inform the economic allocation of GHG emissions between the different products derived from sugar cane. This information only became apparent upon discussion with people in the field.

Problems in calculating land use change emissions

PAS 2050 gives default figures for land use change emissions for 16 countries. If the country of production of an agricultural product to be carbon footprinted is not included in PAS 2050, the value has to be calculated by the analyst using IPCC (2006a) methods. This presents two problems: a certain degree of technical knowledge and expertise is required to carry out these calculations; and the amount of time needed to estimate these emissions might be more than is feasible for many commercial studies with limited resources available.

Another problem arises from the fact that many users of PAS 2050 may not actually visit the farms concerned. This makes choosing the correct preconversion forest (or other vegetation) type more difficult, with potentially large consequences for the resulting product carbon footprint. Without firsthand information on the vegetation in question and the support of experts, it might be impossible to judge whether the amount of biomass in the vegetation assessed is closer to the lower or the higher end of the range of possible values defined by IPCC (2006a), but choosing the default value might lead to a large overestimation of land use change emissions. There might be cases where a farm visit cannot help with these decisions (if, for example, no natural vegetation remains near the farms); but in cases where it does, as with the case studies, the farm visit suggested that even the lower end of the range of possible IPCC values might still overestimate biomass stocks at the sites analyzed.

Country-specific default values for emissions from the conversion of forest land to cropland quoted in PAS 2050 appear to be based on the forest type with the greatest amount of above-ground biomass within a country (although this is not clearly stated). For example, the CO_2e emissions from the conversion of tropical forest to annual cropland for Mozambique assume that the forest converted was tropical moist deciduous forest. This forest type has a greater amount of above-ground biomass than does the other broad forest type occurring in Mozambique—tropical dry forest. This means that emissions resulting from land use change will be greater for the conversion of the former than the latter, with the difference amounting to more than double. Depending on the exact location of the farms under analysis, this means that consulting the default table in PAS 2050 can lead to a large overestimation of emissions; however, as the calculation of these emissions can be time-consuming and require a certain level of expertise, it is likely that many users of the PAS 2050 will just employ these defaults if their country of interest is listed. Considering that the GHG emissions resulting from land use change have a major impact on a product's carbon footprint, this can become a very important issue, and it should probably be pointed out more clearly that the PAS 2050 figures represent the highest possible emissions per country and land use change category, and that users should make any effort to investigate whether these defaults are appropriate to their individual cases. The reason why PAS 2050 gives figures for the highest possible emissions is probably that, in the case of the previous land use being unknown, a worst-case approach has to be applied.

As land use change and resulting GHG emissions can have an overwhelming effect on product carbon footprints according to PAS 2050, and are more likely to be important for developing than industrialized countries, the uncertainties and methodological problems discussed here will have a larger impact on the carbon footprint of agricultural items produced in developing countries. Because the magnitude of GHG emissions from land use change is mainly determined by the amount of above-ground biomass in the preconversion vegetation, the impacts of deforestation will be greatest around the equator and decrease north- and southward as natural productivity also declines. If the inclusion of land use change related emissions is not to disadvantage developing countries unfairly, it is important to address these issues and further develop accessible databases with figures for more countries and different ecological zones and vegetation types.

Issues Not Covered by PAS 2050

In addition to the problems in applying PAS 2050 as discussed above, analysis of the case studies highlights several issues of potential importance that are not covered by PAS 2050, and which should be considered during the further development of future carbon footprinting methods.

Perennial crops sequester carbon in above- and below-ground biomass. PAS 2050 does currently not include this carbon benefit, which will apply to agro-forestry systems such as coffee, cocoa, and tea. Root biomass has been shown to contain a significant amount of carbon for sugar cane grown on Mauritius (8.91 t CO_2e/ha at a cane yield of 87.5 t/ha; Nayamuth & Cheeroo-Nayamuth, 2005), so its inclusion could have an impact on the final carbon footprint. The reason for current the exclusion of above- and below-ground carbon sequestration is probably a lack of precise, region-specific data.

Another area of potential carbon efficiency not considered by carbon footprinting methodologies at present is the increase of soil carbon through the application of organic fertilizers. This operation will be carbon neutral in situations where plant matter, such as leaves, is returned to the soil after harvest; but the application of organic amendments originating from outside the system assessed will lead to a genuine increase in soil carbon, which probably should be included in GHG calculations as a carbon sink if data are available.

Conclusion

Carbon footprints were calculated for four products according to the methodology specified in PAS 2050. Considerable data were required in order to apply this method to the tropical products, and even after spending 55 person days in the relevant countries some uncertainties remained in the understanding of the production systems. The largest impact on the carbon footprint of the Zambian sugar was the land use change. However, on Mauritius, because the agricultural fields had been cleared of forest prior to 1990, these emissions were not included in the footprint. The footprint for fresh pineapple was dominated by the emissions related to the air freight to Europe. In contrast pineapple jam had relatively low emissions from transport, as it was shipped to Europe.

These results show that PAS 2050 can be applied to tropical goods. The major constraints to its application to tropical regions relate to the considerable effort needed for data collection and the high level of expertise needed to estimate the GHG emissions related to land use change. Although this chapter has presented some interesting results in their own right, the main purpose in calculating the carbon footprint according to the PAS 2050 methodology was to enable the sensitivity analysis of key variables, which is presented in the next chapter.

CHAPTER 5

Subjectivity, Uncertainty, and Impact of Methodology on Final Results

Summary

The subjectivity and uncertainties inherent in carbon footprinting are explored in this chapter. First the impact of data choice is reviewed to determine how different datasets may affect the overall carbon footprint calculation, with the example of transport emission factors. Emissions from land use change are then discussed, focusing on the difficulties faced in accurately calculating emissions, the use of default emission factors, and the implications for less developed countries. The subsequent section explores some major differences between carbon footprint methodologies by adding or excluding several key variables from the footprint calculation, showing how products from less-developed countries may be affected, depending on the choice of method. Finally, this chapter summarizes some of the challenges faced when trying to calculate an accurate carbon footprint, such as primary data collection.

Introduction

Carbon footprinting methodologies are largely based upon methods of life cycle assessment, but with a focus on climate change impacts. An important difference between these two tools, however, is their rigidity; LCA is a flexible tool for analysis of products or processes, often used to determine which of two (or more) "pathways" provides the greatest environmental efficiencies. The inherent flexibility of LCA means that the datasets and system boundaries selected by an LCA practitioner will vary from study to study, depending on the aim of a particular analysis. Because of this element of flexibility inherent in LCAs, the results of global warming potential obtained from an LCA calculated by one practitioner should not be used as a benchmark for comparing against a different practitioner's calculation. In contrast, carbon footprint and accounting methodologies such as PAS 2050 are intended to enable the comparative analysis of products, even when the analyses have been calculated by different practitioners. In order to achieve this comparability, carbon footprint practitioners should adhere to a set of rules, boundaries, and datasets. While this approach may be valid when all practitioners use the same carbon accounting methodology, the use of different accounting methodologies—each with different rules, boundaries, and datasets—renders any comparison of results impossible. The purpose of this chapter is to explore the subjectivity and potential uncertainty in carbon footprint calculations. An appreciation of such issues will enable analysts to make comparisons between results when the methods are comparable, but will also highlight the risk of making comparisons between non-comparable accounting methodologies.

The Impact of Data Choice

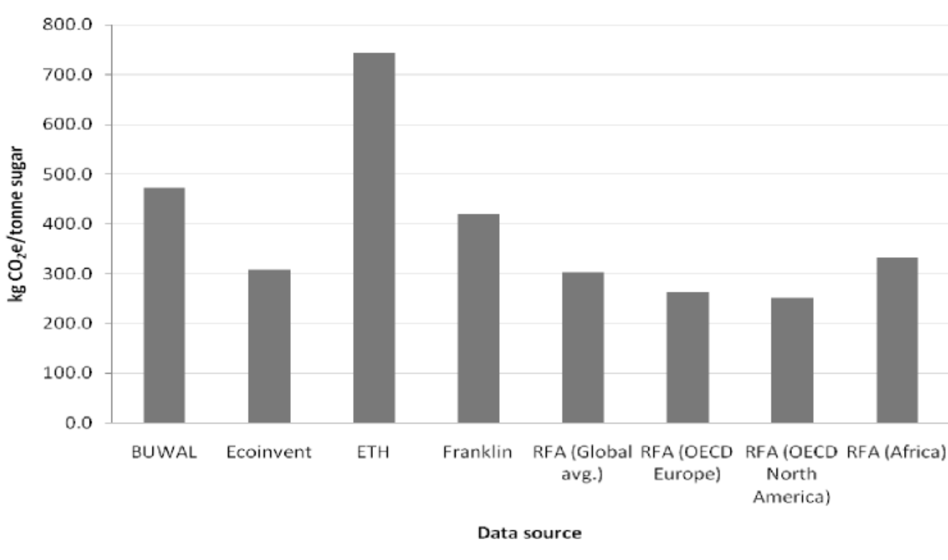
Secondary datasets representing the environmental burdens associated with different products and processes are fundamental to standard LCA and carbon footprinting practice. However, variations between different databases often arise due to the use of different data sources and assumptions. As an example, consider variations in data relating to emissions from transport.

The transport of sugar from a refinery in Zambia to a port 2,000 km away, by truck, is presented here to demonstrate the variation between results depending on which dataset is used (Figure 5.1). ETH reports the emissions of a 16-ton truck at more than double that reported by Ecoinvent, yet ETH often prepares data for Ecoinvent; thus the two datasets are often thought to be interchangeable. In actual fact, none of the LCA database values in Figure 5.1 are interchangeable, because they each have a different method of calculation. For example, the BUWAL value is based on the production and burning of fuel, and assumes that a truck carries on average, 50% load; Ecoinvent includes the production, maintainance, operation, and disposal of the truck, as well as a proportion of emissions from the construction, maintainance, and disposal of roads; ETH includes the production, maintainance, operation, and disposal of the truck, as well as emissions from road construction (but not maintainance or disposal), and assumes 40% vehicle efficiency; and Franklin includes truck and fuel production and use only.

Importantly, of the datasets presented in Figure 5.1, only the UK Renewable Fuels Agency provides transport emission values disaggregated by geographic region (Table 5.1); the difference in road and vehicle condition can greatly impact fuel consumption over long distances.

Similar differences are found between secondary data on rail freight. There is less variation among data regarding air freight, exept when comparing domestic and international flights. That said, the impact of air travel is far higher than those of road

Figure 5.1: GHG emissions from the truck transport of one ton of sugar



Note: This figure shows the variation between different datasets in GHG emissions produced from transporting 1 ton of sugar 2,000 km by road in a 16t truck. Global Warming Potential (GWP) in kg CO_2 equivalent per ton of sugar.

Source: Data are taken from four LCA databases (BUWAL, Ecoinvent, ETH, and Franklin) and the UK Renewable Fuels Agency (2008; truck size not specified).

Table 5.1: Truck transport emissions

Location	Emission factor
OECD North America	0.12556
OECD Europe	0.13158
OECD Pacific	0.13846
FSU	0.15652
Eastern Europe	0.14792
China	0.16254
Other Asia	0.1548
India	0.16684
Middle East	0.16254
Latin America	0.1548
Africa	0.16684
Average	**0.151673**

Source: Adapted from RFA Technical Guidance Part 2 v1.3.

Note: This table shows the percentage of emission factors for truck transport, kg CO_2e /ton-km.

or maritime and so a small difference could potentially have a large impact on the final results.

The impact of data choice is also significant for electricity emission factors, where wider-activity emissions such as from coal and oil mining may or may not be included in the emission factor. Different databases of emission factors are clearly not interchangeable; thus, carbon footprinting methodologies need to specify data sources to ensure that their results are comparable.

Even this limited analysis clearly shows that the relative importance of transport as an emissions source will vary considerably depending upon which dataset is chosen for use; there is almost three-fold difference between the highest and lowest values (Figure 5.1). However, the data needed to calculate a carbon footprint is not restricted to transport, and the same sort of variation exists for other variables, such as electricity or emissions from the production of fertilizer. When all of these variations are combined, considerable differences may arise in the carbon footprint of a product, with the sole variant being the choice of data to use in the calculations. As demonstrated in Table 3.2, many industrialized countries have developed their own country-specific transport emission factors, as this sector is mandatory for GHG reporting under the UNFCCC. This is not the case for LDCs, however, and of the nine countries listed in Table 3.2, none have published country-specific transport emission factors.

The Impact of Land Use Change

As explained in Chapter 4, PAS 2050 gives default figures for land use change emissions for 16 countries. If the country of production of an agricultural product to be carbon footprinted is not included in PAS, the value has to be calculated by the user of the PAS in accordance with IPCC (2006a). This presents two problems: a certain degree of technical knowledge and expertise is required to carry out these calculations, and the amount of time needed to estimate these emissions might be more than is feasible for commercial studies with limited resources available.

Another problem arises from the fact that many users of PAS will not actually visit the farms concerned. This makes choosing the correct pre-conversion forest (or other vegetation) type more difficult, with potentially serious consequences for the resulting product carbon footprint. Without firsthand information on the vegetation in question and the support of experts, it might be impossible to judge whether the amount of biomass in the vegetation assessed is closer to the lower or the higher end of the range of possible values provided by IPCC (2006a), but choosing the default IPCC value might lead to a large overestimation of land use change emissions. There might be cases where a farm visit cannot help with these decisions if, for example, no natural vegetation remains near the farms; but in cases where it does, as in our case studies, the range of potential emissions from deforestation depending on forest type and condition can lead to large differences in carbon footprints.

Country-specific default values for emissions from the conversion of forest land to cropland given in Table E.1 of the PAS appear to be based on the forest type with the greatest amount of above-ground biomass within a country, although this is not clearly stated. For example, the CO_2e emissions from the conversion of tropical forest to annual cropland for Mozambique assume that the forest converted was tropical moist deciduous forest. This forest type has a greater amount of above-ground biomass than the other broad forest type occurring in Mozambique, tropical dry forest. This means that emissions resulting from land use change will be greater for the conversion of the former than the latter, with the difference amounting to more than double. Depending on the exact location of the farms under analysis, this means that consulting the default table in PAS can lead to a large overestimation of emissions; however, as the calculation of these emissions can be time-consuming and require a certain level of expertise, it is likely that many users of the PAS will just employ these defaults if their country of interest is listed. Considering that the GHG emissions resulting from land use change can have a major impact on a product's carbon footprint (see Chapter 4), this can become a very important issue, and it should probably be pointed out more clearly that the PAS figures represent the highest possible emissions per country and land use change category, and that users should make an effort to investigate whether these defaults are appropriate to their individual cases. The reason PAS gives figures for the highest possible emissions is probably that in the case of the previous land use being unknown, a worst-case approach has to be applied.

Land use change and resulting GHG emissions, as calculated according to PAS2050, can have an overwhelming impact on product carbon footprints. These emissions are more likely to be important for developing than industrialized countries, because the greatest increases in cropland area have occurred in developing countries over the last two decades. Because of this, the uncertainties and methodological problems discussed here will have the greatest impact on the carbon footprint of agricultural items produced in developing countries. Because the magnitude of GHG emissions from land use change is mainly determined by the amount of above-ground biomass in the pre-conversion vegetation, the impacts of deforestation will be greatest around the equator and decrease north and southward as natural productivity declines. If the inclusion of land use change–related emissions is not to disadvantage developing countries unfairly, it is important to address these issues and further develop accessible databases with figures for more countries and different ecological zones.

Uncertainties in the Calculation of Emissions from Land Use Change

When calculating the LUC emissions from conversion of land to cropland, one must first decide the former land-type of the area. Some uncertainty remained among the team members visiting the case study farms in Zambia as to whether the prior land-type, described as "bushland," would constitute grassland or forest (Figure 5.2).

As the IPCC (2006a) guidelines describe land with 5–10% cover of trees of greater than 5m height or with a shrub cover greater than 10% and a height less than 5m as under forest cover, the vegetation surrounding the farms was identified as forest land. The emissions resulting from conversion of grassland are considerably lower than those from forest land. In Mozambique, for example, PAS 2050 reports the emissions from LUC of forest and

Figure 5.2: Sugar farm in Zambia

This photo shows a sugar farm in Zambia. The left ring is sugar cane and the right ring is uncultivated native bushland, which may be classified as grassland or forest.

grassland to annual cropland to be 24 and 3.6 tons CO_2e/ha/year respectively, differing by a factor of 6.7.

The major determinants of the amount of emissions from land use change from deforestation are ecological zone and related forest type. This is illustrated in Table 5.2, where figures are shown for the two ecological zones and associated forest types occurring in Zambia according to IPCC (2006a), which is based on FAO data.

The default figures for above-ground biomass differ by a factor of 2.2 between the two forest types—tropical moist deciduous forest and tropical dry forest (Table 5.2). As the map showing ecological zones in IPCC (2006a) is at a very large scale, it can be difficult to decide which forest type applies to a particular case study area. However, this is an important decision with a potentially very large impact on the carbon footprint of a product arising from land converted from forest (Table 5.3).

Table 5.2: Calculating emissions resulting from land use changes in tropical forests

	Tropical moist deciduous forest			Tropical dry forest			
	default	min.	max.	default	min.	max.	
Above-ground biomass	260	160	430	120	120	130	tons d.m. ha^{-1}
Litter C stocks	2.1	1.0	3.0	2.1	1.0	3.0	tons C ha^{-1}
Soil organic C stocks	65	65	65	38	38	38	tons C ha^{-1}

Note: This table shows the default values and their ranges (where available) for major input variables used during the calculation of emissions resulting from land use change from two tropical forest types to cropland according to IPCC (2006): above-ground biomass, litter carbon stocks of mature forests, and soil organic stocks under natural vegetation in 0–30 cm depth (mineral soils); d.m. = dry matter.

Table 5.3: Changes in carbon stocks resulting from land use changes in tropical forests

	Tropical moist deciduous forest			Tropical dry forest			
	default	min.	max.	default	min.	max.	
Change in C stocks in biomass	125	75	210	55	55	60	tons C ha^{-1} $year^{-1}$
Change in C stocks in litter	2.1	1.0	3.0	2.1	1.0	3.0	tons C ha^{-1} $year^{-1}$
Change in soil C stocks	1.8	1.8	1.8	0.9	0.9	0.9	tons C ha^{-1} $year^{-1}$
Total	128.9	77.8	214.8	58.0	56.9	63.9	tons C ha^{-1} $year^{-1}$
	472.7	285.3	787.7	212.5	208.5	234.1	tons CO_2e ha^{-1} $year^{-1}$
Per year over 20 years, according to PAS	**23.6**	**14.3**	**39.4**	**10.6**	**10.4**	**11.7**	**tons CO_2e ha^{-1} $year^{-1}$**

Note: This table shows the results of calculation of change in carbon (C) stocks in above-ground biomass, litter, and mineral soil resulting from land use change from two tropical forest types to cropland, according to IPCC (2006a), using default values and their ranges (where available). The final figure is the 5% of land use change emissions that is included in the GHG emissions of any product for each year during the 20 years following land use change according to PAS 2050.

In addition to potential difficulties surrounding the decision of ecological zone, Table 5.2 highlights the uncertainties surrounding the default values for each forest type. For "tropical dry forests," this range is very narrow (120–130 tons d.m. ha^{-1}), but for "tropical moist deciduous forests," the range is large and reveals wide variations in productivity and standing carbon stocks within this forest category. The use of the default figure might thus either lead to a significant over- or underestimation of actual emissions, with significant implications for the carbon footprint of a product.

For the case studies from Zambia discussed in Chapter 4, the non-agricultural vegetation lost through land use change was identified as "tropical dry forest," according to the map in IPCC (2006a, p. 4.9, Figure 4.1). Consultation with an expert on African forests confirmed this choice. However, looking at pictures taken of the farms and their surrounding vegetation (e.g., Figure 5.2), this expert advised that the forests on and near the farms were degraded—that is, they do not achieve their potential and contain less biomass than the defaults given in IPCC (2006a), which appear to be defined for undisturbed and non-degraded vegetation. On one of the case-study farms, degradation of the forests was ongoing, through the cutting of wood for charcoal burning (Figure 5.3). In this expert's opinion, in order to achieve a fairer assessment of emissions arising from land use change on these farms, the figure for "tons of dry matter per hectare" used in calculating LUC emissions should be around 20–70 tons C ha^{-1}, and thus considerably lower than the IPCC (2006a) default figure shown in Table 5.2.

Land-type information may be more easily accessible for developed countries, which tend to have better electronic resources, such as soil and climate mapping and record-keeping, as well as more financial capacity to carry out data collection such as land inventories. For less-developed countries such as Zambia, data are often sparse. One scientist at the Max Planck Institute in Germany noted of this problem that "most of the few measurements, which are conducted by scientists locally across the [African] continent, found difficulty to reach the international community due to lack of information technology, efficient data

Figure 5.3: Degradation of woodland surrounding a sugar farm

This photo shows the degradation of the woodland adjacent to a sugar farm in Zambia. The devastation comes from cutting the wood for firewood.

sharing procedure, and high cost of publication in international journals, which forces the results to be published in local journals. Most of these local journals lack online archive system and often their printed copies lack worldwide circulation" (Aghedo, 2007). Long and complex supply chains and large agro-climatic variation also greatly affect the ease with which an accurate LUC calculation can be made, and these characteristics are typical of many less-developed countries, such as Zambia.

The Impact of Including or Excluding Key Variables in the Carbon Footprint

This section explores the impact of inclusion or exclusion of certain emissions categories or rules within a carbon footprint calculation. Including and/or excluding key variables is analogous to considering the differences between different carbon footprint methodologies. Unfortunately, as the details of the different methodologies described in Chapter 2 were not available at the time of writing, it was not possible to undertake direct comparisons between methods. However, by considering the impact of different variables on the final carbon footprint of some case study products, it is possible to understand the importance of differences that may emerge from the different methodologies once they are fully developed. The case studies considered are the same as discussed in Chapter 4, relating to sugar and pineapples. In the analyses that follow, the carbon footprint calculated according to the methodology described in PAS 2050 is taken as the baseline (see Chapter 4 for actual footprint values), and the impact of adding and/or subtracting certain variables from this baseline is used to understand the sensitivity of the carbon footprint to differences in accounting methodologies.

Because the analysis presented in Chapter 4 stops at the receiving port of the export destination country, the impact of important variables further down the supply chain that may differ between methods is not considered here (e.g., inclusion of the use phase or consumer shopping trips). Figures 5.4a–5.7a explore the impact of key variables on the absolute carbon footprint per unit of product, while Figure 5.4b–5.7b show resulting differences from the baseline calculation as percentage changes.

Case Study 1: Sugar

Figure 5.4 illustrates the consequences of including or excluding certain variables from the carbon footprint of sugarcane at the farm gate. Details on the baseline calculation can be seen in Chapter 4, and it should be noted that land use change emissions were included only in the baseline footprints of sugarcane produced on Farms A through C and applied to sugarcane processed in Refinery A.

Removing fertilizer N_2O emissions

A major source of agricultural GHG emissions is the release of N_2O following fertilizer application (Mosier et al., 2004). By omitting this emission source, overall sugarcane production footprints are reduced by up to 32%. The largest impact on absolute carbon footprint is on Farm A, with a decrease of over 18 kg CO_2e per ton of sugarcane. Carbon footprints published for organically produced fruit by Soil & More (Soil & More International 2008a, b), using the TÜV Nord carbon footprinting standard (see Chapter 2), appear not to include N_2O emissions from organic fertilizer applications. No organic fertilizer additions could be considered in our case studies (see Chapter 4), and the reduction in carbon footprints shown in Figure 5.4 is based solely on inorganic fertilizer applications; however, the graph highlights the importance of N_2O emissions following nitrogen fertilization, and it is strongly recommended that both inorganic and organic nitrogen additions should be included in any carbon footprint calculation for agricultural products.

Rounding of final reported figure

If the final carbon footprint figure is rounded to two significant figures, the impact in both percentage and absolute terms is very low for sugarcane. PAS 2050 requires rounding to a single precise figure (which might be displayed on a carbon label) because rounding is expected to ameliorate the uncertainties attached to the calculations to some extent.

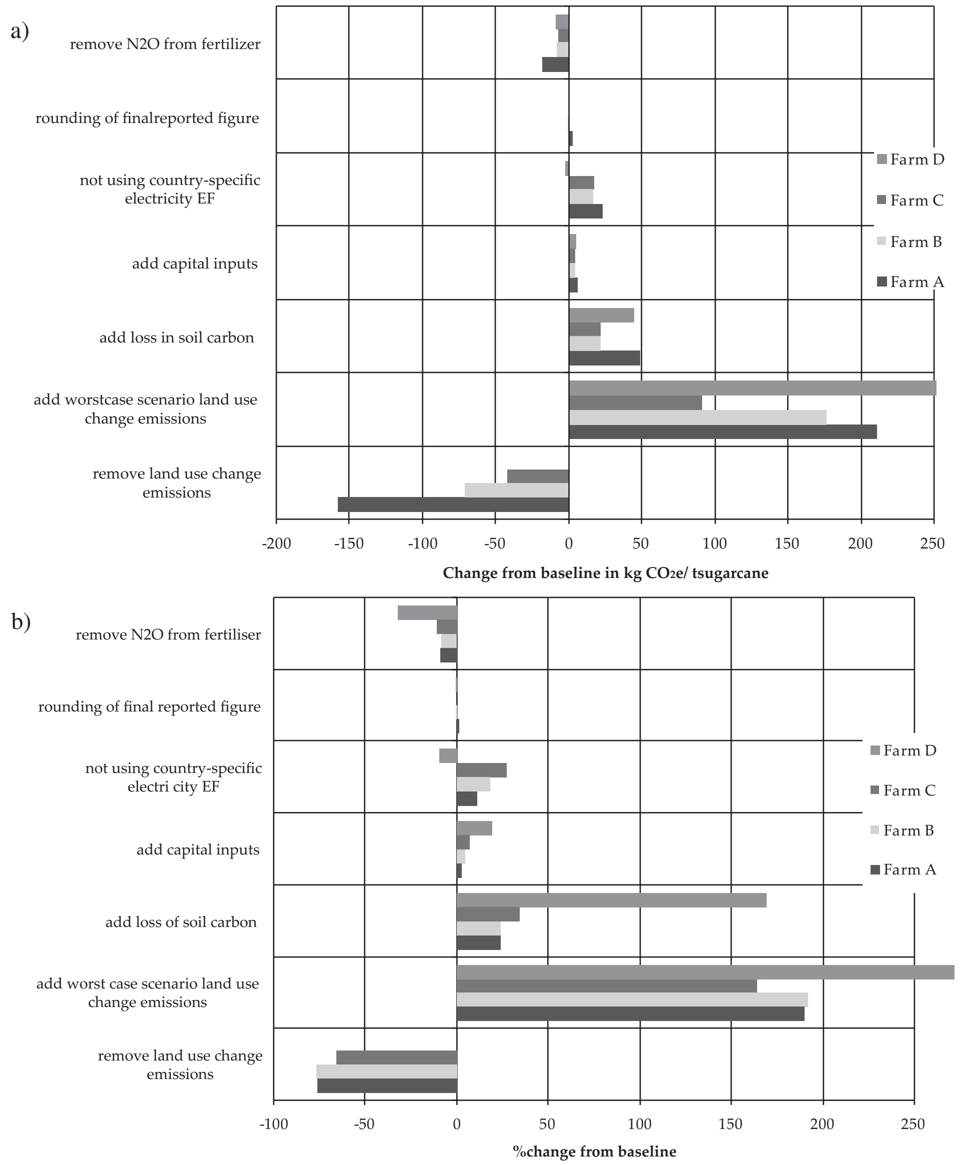
Electricity emission factor

The consequences of not using a country-specific emission factor for electricity are different for farms in Mauritius and Zambia; electricity in Zambia is generated almost solely from hydropower, whereas the electricity mix on Mauritius is largely based on fuel oil and coal, resulting in very low and high country-specific emission factors, respectively. The footprint of sugar from Farm D would be reduced by 10% if an average Africa emission factor (International Energy Agency Data Services, 2007) were chosen instead of the country-specific value used for the baseline calculation, which was developed according to CDM guidelines and is exceptionally high in comparison with all other countries listed in International Energy Data Services (2007). Such a situation might occur if a carbon footprinting methodology did not specify that the user has to use a country-specific emission factor, or a country-specific emission factor was not available from easily accessible sources such International Energy Agency Data Services (2007), as was the case for Mauritius. For Farms A to C, this variable change causes increases of around 17 to 23 kg CO_2e per ton sugarcane, although the magnitude of this increase is greater on Farm C than Farms A and B. While all three farms use similar amounts of electricity per unit area, this difference is due to Farm C's lower total carbon footprint, with land use change emissions dwarfing other emissions categories less than for the other two farms.

Adding capital inputs

Accounting for the emissions from production and maintenance of capital inputs (in this case, farm machinery) adds relatively little to the footprint calculations of Farms A to C

Figure 5.4: The carbon footprint of one ton of sugarcane delivered to a refinery



Note: This figure shows the change in carbon footprint per ton of sugarcane delivered to refinery, caused by changing parameters from the baseline calculation. a) Change from baseline in kg CO_2e/t sugarcane; b) percentage change. Baseline is calculated according to PAS 2050. Former land use taken to be tropical dry forest. EF=emission factor

(3–7%). The percentage increase is greater on Farm D (20%) than the other farms because emissions from its land use change (as included in the baseline) dwarf all other emission categories for Farms A to C. Overall, the low use of capital inputs (and therefore low emissions from this source) is typical of developing country production systems. Zambia is listed by the World Bank as a "low-income economy," and large amounts of manual labor were employed on all farms visited. The relatively low increase in footprint when including capital inputs thus reflects a "carbon efficiency" typical of many products from LDCs, but is currently excluded from all methodologies listed in this report. It is important to remember, however, that the large emissions from land use change dwarf the relative importance of this emission category for Farms A to C. On farms where no land use change has occurred, such as Farm D, capital inputs can have a significant impact on the overall carbon footprint.

No firm conclusions on the effect of the economic development on the impact of capital inputs could be shown from our case studies. The calculation of emissions from capital inputs presented here was based on the amount of diesel used per hectare, which in itself relates to the size and amount of machinery used. Overall diesel use per ton of sugarcane produced was similar for all farms (1.6–2.2 liters), with one of the farms in Zambia (a World Bank "low-income economy") having the highest use of diesel, even slightly higher than the farm on Mauritius ("upper middle-income economy").

Loss of soil carbon

Carbon is released from cultivated soils due to activities such as plowing. This is currently excluded from the PAS 2050 methodology, due to the difficulty in accurately estimating this emission source. However, it is being considered for future revisions, and an LCA analyst might choose to include it in their analysis. As illustrated here, including loss of soil carbon in the calculation causes relatively large increases in the footprints of all farms, with Farm D particularly affected (over 170% increase) due to its comparatively low overall footprint. Even on Zambian farms, where LUC emissions tend to dwarf all other emissions, the inclusion of soil carbon losses results in an increase of up to 34% in total footprint. The figure used for the calculation of soil carbon losses per hectare was taken from Woomer et al., (1997) and relates to continuous vegetable cultivation in Kenya. This figure was applied to all four case study farms due to the lack of published figures more specific to sugarcane and the countries analyzed. Thus the differences in the results are due solely to the different yields on the farms. Further research into this issue is needed, to enable better assessment of the impact of this emission source, as well as the potential of soils to sequester carbon.

Land use change: worst-case scenario

Deciding how to calculate emissions from LUC clearly poses the greatest challenge when calculating the carbon footprint of sugarcane. Currently, PAS 2050 states that: "where the country of production of the agricultural crop is not known, the GHG emissions arising from land use change shall be the highest potential emissions arising from land use change for all countries (i.e., it shall be assumed that GHG emissions associated with land use change are equivalent to those emissions arising from the conversion of forest land to annual cropland in Malaysia)." The result of making this worst-case scenario assumption is an increase in GHG emissions of nearly 2000% on Farm D (Figure 5.4b). This is much higher for Farm D than Farms A to C, because the baseline for Farm D does not include any land use change emissions, as all cultivation was on long-established fields. In contrast, land use change emissions from converting tropical dry forest to cropland were included in the baseline figure for Farms A to C, so that assuming the worst-case scenario adds less to these farms. The footprints of Farms A, B, and C are affected by up to over 190% from this assumption; although this is considerably less than Farm D, it is still very high. Including such requirements into carbon accounting methodologies presents a major problem to producers of commodities such as sugar, which are often sold either as multiple-origin products or as ingredients within a product, the source of which may vary seasonally and may therefore be unknown. However, the requirement in PAS 2050 to include this worst-case scenario in GHG assessments in cases where no data exist on country of origin, is assumed to provide enough incentive to users of the PAS to make every effort to report the origin of agricultural products or find it out from their suppliers. It was felt by the developers of PAS 2050 that allowing the use of average data in these cases would encourage poor reporting in areas where land use change emissions could have significant impacts.

Exclusion of land use change emissions

At present, the methodologies reported by TÜV Nord, Soil & More, Casino, and METI (Japan) do not include LUC emissions within their calculations. The result of removing this emission category from the calculation reduces the overall footprint of Zambian farms by up to 77%, with the footprint of Farm A decreasing by nearly 160 kg CO_2e. The impact on Farm A per ton of cane produced is greater than Farms B and C due to its lower yields per hectare. Farm D remains unaffected by this variable change, as land here was converted prior to 1990, and thus this emission source was not included in its baseline calculation.

Increasing the system boundaries of sugar carbon footprints to include refining and transport to a European port results in a decrease in the relative importance of some emissions sources within the carbon footprint (Figure 5.5).

Refinery A was located in Zambia and processed sugarcane grown on land converted from native vegetation. As a result, the carbon footprint of the sugarcane was very high compared to Refinery B, where land use change emissions did not occur for the cultivation stage of the cane. This is why some variables that relate to the cultivation of the sugarcane have a lower percentage impact on sugar produced in Refinery A than B. Because sugarcane contributes over 99% to the carbon footprint of sugar at the refinery gate, emissions caused during the cultivation stage still have a very significant impact on the carbon footprint of refined sugar, but this is reduced in comparison to the cropping stage, due to the addition of overseas transportation and, in the case of Refinery B, economic allocation between byproducts.

The location of Refinery A in a landlocked country, far from a port, means that any produce destined for export must be transported long distances by road or rail prior to international shipping. Refinery B is located relatively close to a port; thus, its transport emissions are comparatively very low.

Allocation

Defining the method of allocation is important for the footprint of sugar from Refinery B. This is because several products come from this refinery, whereas the sole output of Refinery A is sugar. When changing from economic to mass allocation, the carbon footprint of sugar from Refinery B decreases by about 50%. This is because sugar accounts for only 22% of the mass of the byproducts from this refinery, whereas it accounts for over 90% of the economic revenue.

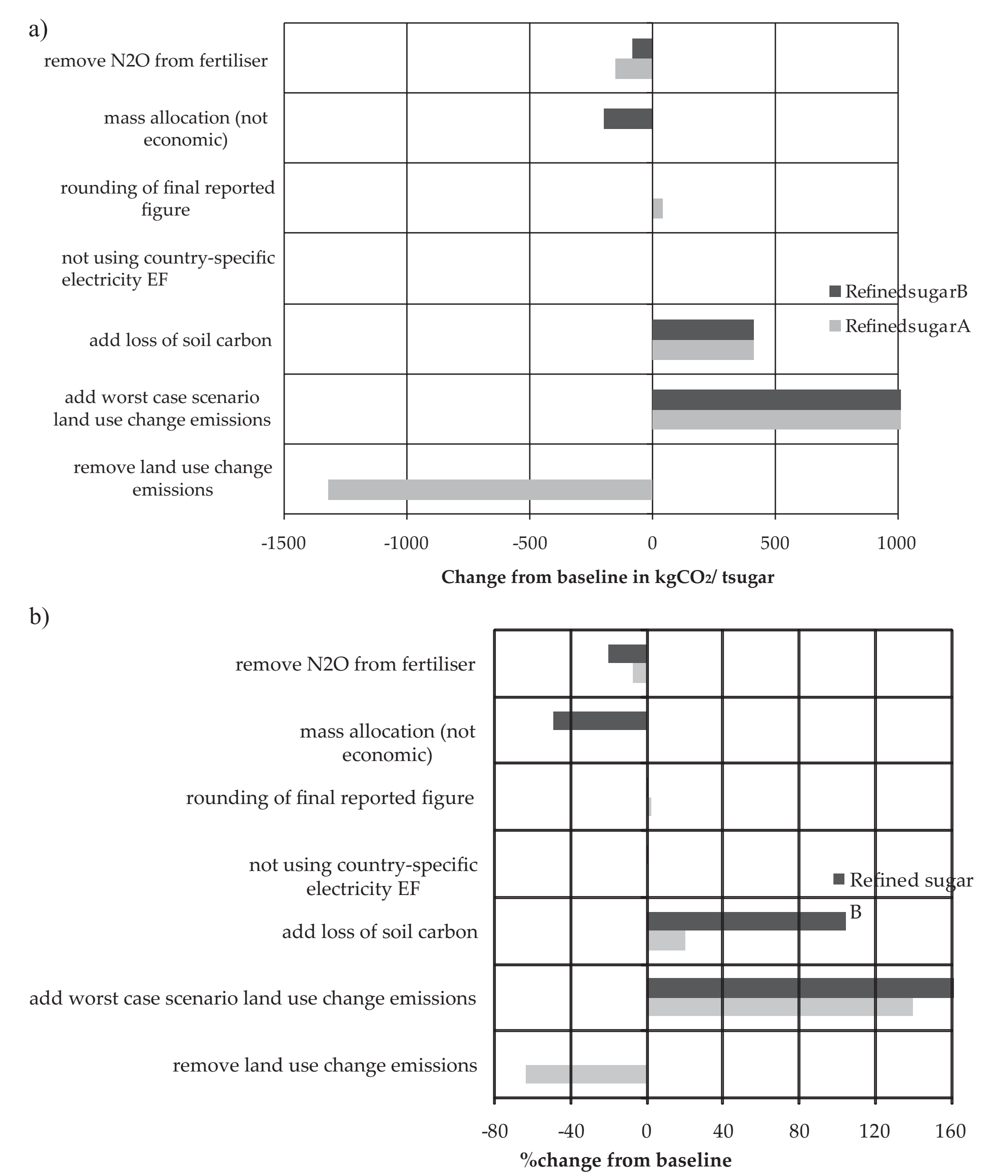
Non-specific electricity emission factor

The overall carbon footprint of refined sugar is not affected by the choice of electricity emission factor for refinery operations. This is because Refinery A does not use any grid electricity at all, and Refinery B uses only small amounts, with the rest of the energy needed being generated from bagasse.

Loss of soil carbon

The inclusion of this variable in the refined sugar footprint causes a considerable increase, at around 400kg CO_2e per ton of refined sugar from both refineries. As a percentage, however, this increase is lower for Refinery A, as this refinery has much higher overall emissions due to the inclusion of LUC emissions and relatively long road transport distance.

Figure 5.5: The carbon footprint of one ton of refined sugar delivered to port



Note: This figure shows the change in carbon footprint per ton of refined sugar delivered to a European port, caused by changing parameters from the baseline calculation. a) Change from baseline in kg CO_2e/t sugar; b) percentage change. Baseline is calculated according to PAS 2050. Former land use taken to be tropical dry forest. EF=emission factor

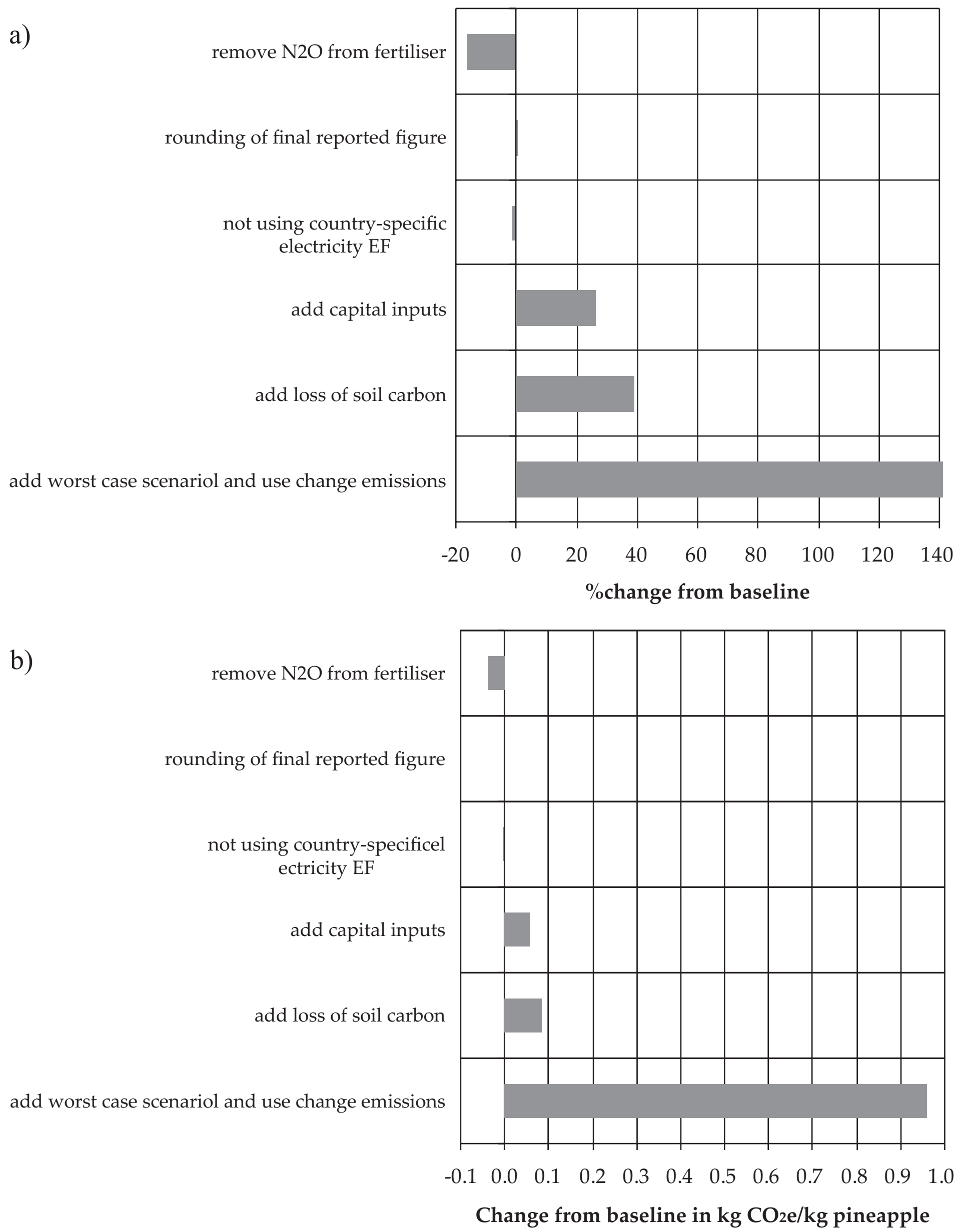
Land use change: worst-case scenario

The impact of assuming worst-case scenario emissions for LUC is significant for refined sugar, at over 1,000% increase for Refinery A and around 140% for Refinery B. Even though its relative importance has declined compared with the footprint of sugarcane, land use change emissions still have a major impact on the final footprint. The issues of calculating and including land use change emissions in product carbon footprints are worthy of further research and data development.

Case Study 2: Pineapples

When analyzing the impact of data inclusion or exclusion for the fresh pineapple carbon footprint, similar issues as for sugarcane can be seen (see Figure 5.6). Land use change was not included in the baseline calculation here, as it occured prior to 1990.

Figure 5.6: The carbon footprint per kilogram of pineapple at the farm gate



Note: This figure shows the change in carbon footprint per kg of pineapple at the farm gate, caused by changing parameters from the baseline calculation. a) Change from baseline in kg CO_2e/kg pineapple; b) percentage change. Baseline (0%) is calculated according to PAS 2050. EF=emission factor

Removing fertilizer N_2O emissions

With emissions of N_2O from fertilizer comprising 16% of the carbon footprint of pineapple production, excluding this variable from the calculation has significant impact on the overall result. As previously mentioned, the method of Soil & More currently omits N_2O from organic fertilizers. No organic fertilizers were used on the pineapple farm analyzed, and all emissions shown here arose from synthetic fertilizer application.

Rounding of the reported figure

As with sugar production, rounding of the final reported carbon footprint figure has a negligible impact.

Electricity emission factor

The electricity mix on Mauritius comprises largely conventional thermal sources such as coal, oil or gas. The substituted average African emission factor used here is comparatively "cleaner"; thus, replacing a country-specific value with a different one here actually reduces the overall footprint. The magnitude of this impact remains small in this case study, as little electricity is used on-farm. However, for a farm or processing plant with large amounts of electricity consumption, this could have a much larger effect. The use of a regional instead of country-specific emission factor will probably be more common for small countries such as Mauritius, where country-specific EFs for electricity tend to be less commonly available in publications such as International Energy Agency Data Services (2007).

Adding capital inputs

By adding emissions from the production of capital inputs, the pineapple carbon footprint is increased by 26%, although this equates to a very small amount of carbon (less than 0.1 kg CO_2e), as the overall footprint of pineapples is comparatively low. This shows that this emission category can have a significant impact in countries such as Mauritius, where levels of mechanization might be greater than in least-developed countries such as Zambia. A direct comparison with farms in industrialized countries was outside the scope of this study, but it is expected that the greater mechanization in these countries will have a larger impact on the carbon footprint than shown here. At present, none of the carbon footprinting schemes listed in Chapter 2 have stated that they include this emission category in calculations.

Loss of soil carbon

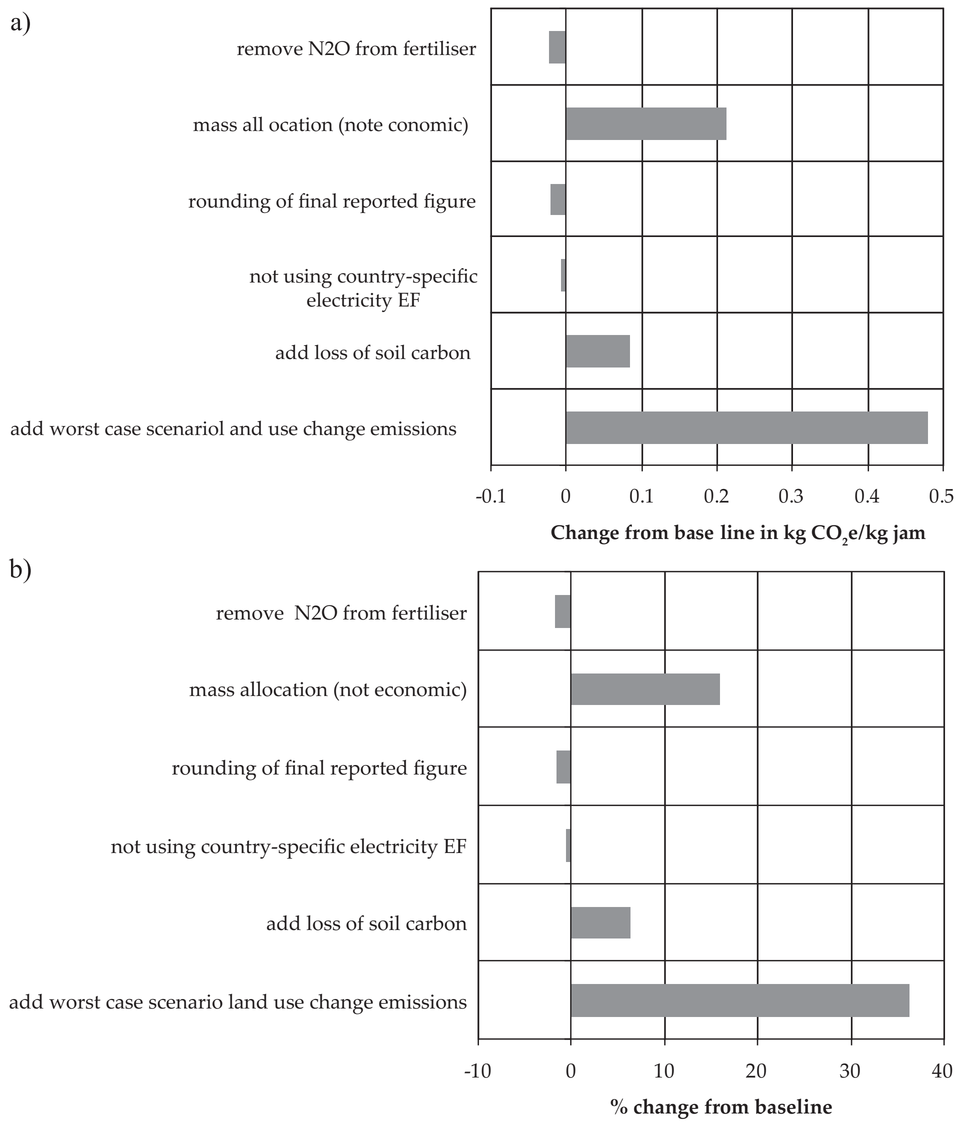
Including emissions from loss of soil carbon, as might occurr in a standard LCA, had the second-largest impact on the overall footprint analyzed here, amounting to a 39% increase in footprint (although this is still less than 0.1 kg CO_2e/kg pineapple). As noted in Chapter 2, this variable is not currently included in any footprinting methods, but will be considered for future revisions of PAS 2050. It is therefore an area in need of scientific research if an accurate figure is to be included.

Land use change emissions

Land use change was not included in the baseline calculation here, as it occured prior to 1990. However, if the origin of pineapples were unknown, a PAS 2050 carbon footprint would assume the worst-case scenario LUC emissions. This is shown in figure 5.6b to result in a footprint increase of over 400%. This is a feasible scenario for a product such as tinned or dried pineapples, the origin of which may not always be clear.

The baseline calculation of pineapple jam (Figure 5.7) includes emissions from pineapples, sugar, glass jars, processing, and transport to UK port. Because pineapples are only one of the inputs to the jam, some of which have travelled over long distances to the processing plant, the impact of inclusion or exclusion of other emissions categories related to the cultivation stage of pineapples becomes less marked. For example, assuming a worst-case scenario for land use change emissions causes an increase of less than 40%, compared with over 400% in Figure 5.6. The magnitude of change from including soil carbon emissions is also decreased, from a 39% increase in Figure 5.6 to a 6% increase in Figure 5.7.

Figure 5.7: The carbon footprint per kilogram of pineapple jam for European export



Note: This figure shows the change in carbon footprint per kg of pineapple jam at the European import gate, caused by changing parameters from the baseline calculation. a) Change from baseline in kg CO_2e/kg jam; b) percentage change. Baseline (0%) is calculated according to PAS 2050. EF=emission factor

PAS 2050 states that emissions should be allocated to different products coming from a system according to the proportional economic value of each product. The alternative, allocating according to the proportional mass of each product, is shown to result in a significant increase in the footprint of pineapple jam (16%). This is because of the diesel used for cooking; more is allocated to other products, which gain a larger part of the revenue than jam. On a mass basis, the split between jam and the other products is equal.

Worker transport

The transport of farm employees to work was excluded from the baseline footprint calculation in accordance with PAS 2050, but it might be included in an LCA study or carbon footprint calculations conducted by Soil & More (see Chapter 2). No data on numbers of workers, their mode of transport, and travel distances were available for the Mauritian case studies, which is why we explore the potential effect of including emissions from worker transport here without presenting any figures.

In the case of farms in Zambia, the short distance of farms from villages meant that most workers walked to work. On Mauritius, it is expected that even if workers travel to the farms by car or public transport, this will involve relatively short distances. This might represent a “carbon efficiency” compared to industrialized countries, where farm workers might travel longer distances, usually by car, which is not currently reflected in some carbon footprint accounting methodologies.

In a comparative study of lettuce cropping in Spain and Uganda (Milà i Canals et al., 2008), travel of workers to the farms was found to be insignificant on the Spanish farms, compared to the amount of diesel used for field operations (8 vs. 251 and 13 vs. 156 l diesel/ha/crop for workers’ transport and field operations, respectively). This means that including this emissions category would not lead to a great increase in the carbon footprint of the Spanish produce, and excluding it does not greatly disadvantage the Ugandan production system, where all workers walked or cycled to work. Of much greater importance was the fact that all work on the Ugandan smallholder farms was manual.

On green bean farms in Kenya, where most but not all work was manual but the majority of farm workers travelled by mini-bus (60 workers per bus, 10 km per day), the reverse situation was found: diesel usage for worker transport was almost as much as for field operations (Milà i Canals et al., 2008), and the inclusion of this category could lead to a significant increase in the carbon footprint at the farm gate. However, total diesel usage was still higher on UK farms producing early green beans by a factor of 1.5; for late beans, UK and Kenyan farms used almost the same amount of diesel for worker transport and field operations. Ugandan smallholder farms, on the contrary, used significantly lower amounts of diesel for field operations and none for transport. The difference between Ugandan and Kenyan farms is probably due to the fact that the farms analyzed in Kenya grew beans for export with higher levels of mechanization and infrastructure. The Ugandan farms visited were all smallholder farms selling mainly or exclusively to local markets, where workers travelled on foot or by bike. It is also worth noting that GHG emissions from both field operations and transport of farm workers were negligible once air freighting of the produce to its European markets was included, which means that the inclusion or exclusion of this potential carbon efficiency achieved in the developing country will have no impact on the total carbon footprint for produce transported over long distances by air.

The Reality of Data Collection

Through visiting Zambia and Mauritius to collect data on sugar and pineapples, it has become apparent that considerable time and resources are needed to collect data that enable the calculation of accurate carbon footprints of tropical food products. Even after spending several weeks working with local farmers and processors, some assumptions about certain processes had to be made as part of the analysis, and certain default data had to be used for calculating LUC emissions.

Varying levels of interest and willingness to participate were shown by stakeholders in the two case study countries. There were many positive and helpful participants but also some skepticism about carbon footprinting in general. Some producers showed interest in participating in the study but were reluctant to part with information to the level of detail needed for accurate footprint calculation. A lack of willingness to participate was also encountered by some processors, owing to a perceived conflict of interest with their own footprinting activities; this highlights the current subjective nature of carbon footprinting and the need for a streamlined approach. Even so, a large amount of detailed data was collected from helpful and willing participants.

Primary data collection, essential for accurate footprint calculation, also increases the level of detail and thus complication of calculation. For example, if on-farm practices vary year-to-year or even within one year, the calculations can account for this by means of complicated equations. In reality, the level of time invested in calculating carbon footprints here is unlikely to be available for most food products.

Conclusions

It is clear that the overall carbon footprint of a product will vary enormously according to the accounting methodology used. Of particular importance are the emissions related to land use change. Where land use change occurs in tropical countries, these values are likely to dominate the footprint, and so their inclusion (or not) in any footprinting methodology will have a major impact on the final results of that methodology. In addition there are large uncertainties associated with the calculation of emissions related to LUC. Even though the IPCC provide detailed guidance on how to calculate LUC emissions, there remains significant room for error and manipulation in these calculations. Of particular worry are the large-scale aggregated descriptions of different forest types in different countries and the uncertainty surrounding their carbon content.

In a way the very technical nature of the IPCC guidelines for calculating emissions from LUC can engender a false sense of security in their accuracy. This would be particularly true for analysts who did not visit the country of concern and had no specialist forestry knowledge. In reality, characterizing existing land use in tropical countries can be difficult even after a site visit, especially when some of the forests are degraded. This task becomes even more difficult if there is no natural vegetation left in an area and analysts are required to "guesstimate" what natural ecosystems may have existed prior to conversion to agriculture. It is indeed unfortunate that one of the key contributors to the carbon footprints of food items is also one of the most difficult to quantify. This misfortune is worsened by the potential inequity of only accounting for recent land use change in carbon footprint, a fact that brings a far greater burden on tropical developing countries than it does on developed countries, which were generally deforested decades if not centuries ago. However, if GHG emissions from land use change of, for example, 100 years ago were included, the impact allocated over 100 years per unit of product would be much lower.

The impacts of LUC on a product carbon footprint are maximized if the worst-case situation is assumed. For all of the case study examples considered, the inclusion of the worst-case LUC led to a massive increase in the footprint of the products. This reflects the differences between the emissions from LUC in the case study countries. In Zambia, LUC emissions calculated according to PAS were much lower than for the worst-case scenario (Malaysia); and in Mauritius, where no LUC emissions occurred, the inclusion of data from the worst-case situation resulted in a massive increase in the carbon footprint.

The inclusion of some other variables in the footprint—such as loss of soil carbon due to soil management, or change in electricity emission factor—also brought about some reasonably large changes in the overall result, but none were as large as those factors relating to LUC. However, where carbon footprints are calculated with methods that do not require the inclusion of land use change emissions, the relative importance of these other variables will increase.

CHAPTER 6

Conclusions and Recommendations for Development-Friendly Carbon Footprinting Schemes

Summary

This chapter concludes the report by listing some key characteristics of agricultural production and trade in less-developed countries that make them particularly vulnerable to carbon footprinting. In combining these features with insights gained from this research, the chapter provides a number of recommendations for improving the utility of carbon footprinting to less-developed countries. These recommendations have a particular focus on land use change, information and data collection, calculation, and communication.

Introduction

Carbon accounting and labeling for products are new instruments of supply-chain management that may affect developing countries' export opportunities. These instruments analyze and present information on greenhouse gas emissions of products in an attempt to identify major sources of emissions in supply chains. Once the emissions from different parts of a supply chain have been identified, it is hoped that actions will be taken to reduce emissions in a timely and cost-effective manner. Within the food sector there are typically four forms of action that can be taken:

1. Voluntary responses by companies to the challenge of climate change, which may also bring commercial advantage through enhanced marketing and public relations.
2. Action by governments to encourage companies to reduce their emissions. These may also help governments meet their international obligations for reductions in greenhouse gases (GHGs).
3. Action by retailers to stock only products that achieve a certain "standard" in terms of their carbon footprint.
4. Action by retailers to place a label on products that informs consumers about the carbon footprint of that product, thereby enabling consumers to make informed choices between products.

At least 16 different methodologies for calculating the carbon footprint of products have been developed since 2007 or are still under development. Some of these methodologies are publicly available and provide users with detailed advice on how to undertake a carbon footprinting exercise (e.g., PAS 2050, developed by the Carbon Trust, UK), while others are confidential.

The designers of these schemes are caught in a dilemma: on the one hand they have to respond to policy and corporate agendas, to create new ways of responding to climate change challenges; while on the other, designers rely on very rudimentary knowledge about actual emission patterns related to the varied production systems that occur around the globe. This is because the underlying scientific understanding of greenhouse gas emissions from agriculture is only partially developed. Unfortunately knowledge about the emissions of greenhouse gases is particularly scarce in the area of production and processing activities in developing countries.

As a result of the pressures placed on designers and users of carbon accounting and labeling instruments, there is a risk that carbon accounting and labeling instruments will not properly represent the complexity of production systems in developing countries.

The Situation in Developing Countries

Developing countries tend to have a set of characteristics that make their economies particularly susceptible to the introduction of carbon accounting and/or labeling of food items in more-developed countries. These characteristics are:

1. They tend to be distant from their markets and therefore have a high dependence on long-distance transport to deliver their goods to market. Many products are transported by ships, which tend to emit few greenhouse gases per ton/km.[1] However, some high-value fresh products are transported by air, which emits large amounts of greenhouse gases per ton km.
2. Some crops in developing countries suffer from low and variable yields. This variation may be related to annual changes in weather, presence of pests, absence of key inputs, and/or insufficient technical knowledge. Regardless of the cause, low yields contribute to high carbon footprints of food items, which are expressed per unit weight.
3. As the production of food for export is a relatively new enterprise for many developing countries, they have had to clear previous natural land to enable the creation of cropland and pasture. This is in contrast to most of the nations in Europe and North America, who created their agricultural land many decades or centuries ago. The conversion of forests and grasslands to cropland results in the loss of carbon stored in their vegetation, and also loss of carbon from the soil. The amount of carbon lost during any land use change (LUC) depends upon the exact nature of the forest or grassland under conversion. Typically tropical forests store a lot of carbon in their trees and soils, and thus these forest types release the most carbon when they are converted. Other forest types, like some of the patchy forest typical of semi-arid areas of Africa, release less carbon than tropical forests when they are converted to agriculture. There is a similar variation in the amount of carbon released by different types of grassland when they are converted to cropland. The Intergovernmental Panel on Climate Change (IPCC, 2006a) has derived methods of estimating the amount of carbon released from the conversion of different forests and grasslands, but these methods require good knowledge of the relevant ecosystems and carbon accounting techniques. Some carbon accounting methodologies do not consider the emissions from land use change, but many do. The PAS 2050 methodology requires that emissions from all land use change that occurred after 1990 be included in the carbon footprint of a product. For example, if sugar is grown on land that was converted from forest to grassland in 1991, then the emissions from this conversion must be considered. However, if a neighboring farm had converted their land to grow sugar in 1989, then there would be no need to consider emissions from LUC. Typically the emissions from LUC are

among the largest sources of emissions in the carbon footprint of crops produced in developing countries. Because of this, it is important that calculations of these emissions are done correctly. This can be difficult in developing countries where relevant data relating to the distribution of current and historical land uses are scarce or absent. Not only are there technical issues surrounding the calculation of emissions from LUC, but in addition there is the ethical issue that most developed countries do not need to include this source of emission, as they cleared their forests decades or centuries ago.

4. Many tropical developing countries export goods derived from tree crops, such as coffee, cocoa, tea, fruit, and nuts. While trees themselves sequester carbon, the forest soils tend to sequester far more carbon than the above-ground biomass. Currently few carbon footprinting methodologies recognize the positive contribution made by carbon stored in trees used to produce food, or that sequestered in the soil. Thus, many developing countries are in the situation where they have to declare emissions from LUC but cannot claim benefits from the management of tree crops.
5. There tends to be a deficiency in data and information relevant to developing countries when compared to more-developed countries. As a result, carbon accounting and footprinting analysts are required to use very imprecise and uncertain datasets that relate to very large geographic scales. These may mask important differences between different countries, or regions within a country.
6. Some of the commodity products produced by developing countries, such as sugar, can be delivered to the final marketplace in a blend of product derived from more than one country. Where the origin of a commodity is unknown, problems arise when calculating carbon footprints, as the calculations require the use of certain country-specific data. If the country of origin is not known, then some accounting methodologies require that data from the worst-case scenario be utilized. These worst-case scenarios can be much larger than the real data from the country of origin would be. For some variables, such as land use change, the worst-case scenario relates to the conversion of tropical forest in Malaysia. It is debatable how relevant these figures are to crops produced in Africa, South America, or central Asia.
7. Developing countries tend to engage in minimal processing of the food they produce. Not only does this mean that they may lose the potential of creating added economic value, but it also means that they lose the potential "carbon advantages" that could be related to the use of renewable energy, low capital inputs, and a shift from air to ship as means of transport (e.g., fresh fruit and preserved fruit).
8. Very few developing countries have government officials, businesspeople, or academics who are fully conversant with the intricacies of carbon accounting and labeling. As a result they lack technical expertise in relevant topics. However, some of the international companies who operate in developing countries have high levels of expertise, and can also hire skilled consultants to help understand their businesses. It is not clear whether this mismatch of knowledge between government and industry is helpful to the overall development of the country.
9. Relatively few farms and processing plants situated in developing countries will be visited by the analysts who calculate the carbon footprint of the food items they produce. Rather, the farmers will be required to complete a questionnaire on their agricultural practices, and the consultants will use the results of these questionnaires alongside standard databases to help them calculate the carbon footprint. This approach brings two problems. First, the analyst may have an incomplete understanding of the system of analysis, and second, the databases may contain poor data on many developing countries.

10. A problem for small (island) states are inherent constraints that limit their opportunities for emissions reductions. For example, a small island state cannot produce enough volume of a fresh fruit, such as pineapple, to make transport by container ship economically possible, and air freighting of small volumes of high-value varieties every week is the only viable solution.
11. Developing countries that are distant from their markets typically have less access to high-volume shipping systems, which are usually more energy-efficient than smaller container ships (Bolwig and Gibbon, 2009). Coupled with often great distances to port for many African countries and a less-developed rail system, increasing the dependence on less carbon-efficient road transport, this situation has a negative effect on carbon footprints.

Recommendations for Development-Friendly Carbon Footprinting

Given the situation observed in developing countries, several recommendations can be made that may improve the utility of carbon footprints of food products from developing countries. These may be grouped under four categories:

Land Use Change

1. **Work toward an equitable solution for the inclusion of emissions from LUC in carbon footprints.** Science shows that the conversion of forest and natural grassland to agriculture does cause an increase in the emission of greenhouse gases. Science also shows that the amount of emissions vary with location. However, there are ethical issues surrounding the date at which such conversions should be included in carbon footprints. While in many ways 1990 is a sensible baseline, as it ties in with other international agreements, it may also serve to disadvantage those developing countries that have converted land since 1990. Given that many developing countries had relatively little land that was not forest or natural grassland until recent times, the requirement to include LUC in carbon footprints may seem inequitable to some.
2. **Develop better databases of land use and emission factors for developing countries.** If emissions from LUC are to be included in product footprints, then these emissions need to be calculated correctly for the particular parcel of land concerned. This can only happen if the levels of precision and certainty are increased in the databases that provide emissions factors and the historical and current distribution of land cover and land use.
3. **Develop regional worst-case databases.** In order to prevent countries having to utilize data from the global worst case when other data are absent, which may not be of any relevance to their situation, it would be useful if data for regional worst-case situations could be identified and made publicly available.
4. **Consider including benefits derived from tree and bush crops in footprints.** Tree crops can sequester carbon, and the soil under tree crops and agro-forestry systems typically contains more carbon than other forms of cropland. It would be useful to find a way of providing some credit for the carbon sequestered by these systems, and thereby reward their owners and incentivizing the future development of such systems.

Information and Data

1. **Develop emissions databases for agri-ecological zones.** There is an urgent requirement for databases of emission factors and land use change to be developed for tropical and subtropical areas. These databases would normally be developed at the country level, but given the size and biophysical variability of some developing

countries, one set of data may not be suitable to represent the whole country, so there is a need to develop data for several regions in a country. Such an exercise would be resource-intensive, but as many countries share similar biophysical characteristics, there could be merit in simply developing databases for particular agri-ecological zones. This would offer considerable advantages of efficiency and also enable the generation of more geographically-specific data.

2. **Make relevant data more accessible.** All information needed for carbon footprinting of agricultural products should be located in one easily accessible and user-friendly database. Although there are several websites that seek to provide some of the relevant data, none of the current ones are complete, and their presence is not well signposted to naive users.
3. **Provide training and support in record-keeping.** If small-scale producers, producer cooperatives, and traders do not maintain good and accurate records of inputs and yields, then there may be a need to make more assumptions when calculating footprints than if they had good and accurate records. It may be necessary to train such farmers in record-keeping, in order to ensure that they are not disadvantaged in comparison with large-scale producers/traders, who may have better record-keeping and access to expertise to help with footprinting.

Calculation and Communication

1. **All calculations of carbon footprints should be published on a public database.** It should not be permissible for retailers or others to declare carbon footprints on consumer-facing labels or websites unless the details of the calculation are published in a public place. These sites should also clearly state all the assumptions made when calculating the carbon footprint. Such publication would enable governments, NGOs, journalists, the public, and producers to scrutinize the data and the methods, and judge the accuracy of the results.
2. **Declare the intensity of data collection.** When publishing information on carbon footprints, it should be stated whether or not the consultants actually visited the countries and farms analyzed. This is important, as carbon footprints based on primary data are more likely to be accurate than those based on secondary data.
3. **Recognize the subjectivity and uncertainty in carbon footprints.** Footprinting methodologies need to reduce the level of subjectivity inherent within them. Relatively little work is reported in the literature on the subjective nature of LCAs and carbon footprints, and the differences that may arise if different analysts consider the same product or process. This issue is important where these analyses may impact consumer-facing carbon labels, influence the purchasing decisions of retailers, or become included in policy making (cf. EU Biofuels Directive), which might impact access to markets, subsidies, tax breaks, and so on. There is also a need for footprinting analysts to recognize and communicate the level of subjectivity that is inherent in calculating any carbon footprint. Carbon footprints are intended to be used as tools to inform business, governments, and consumers, so that they can take relevant action to reduce climate change. Unfortunately there is currently a tendency to utilize carbon footprints simply as a means to gain commercial advantage and/or market access. This commerciality is one reason why the details of carbon footprinting methods are not normally communicated to the public. Initiatives for internationally agreed and standardized carbon footprinting methods should be supported.
4. **Footprints should consider including capital inputs.** Not all carbon footprinting methods require that emissions related to the manufacture of capital items be included in the calculations. The exclusion of capital items can comparatively

disadvantage developing country producers if this "carbon efficiency" is not taken into account. For example, developing countries typically utilize human labor instead of machines, and the infrastructure in developing countries is often less established than in developed countries.

5. **Provide more disaggregated consumer information.** Some carbon footprints require that emissions from the use phase of the product be included in the overall calculation. For food items, the main emissions relating to use are from cooking and refrigeration. In products such as coffee, the use phase is so large (30% of the carbon footprint) that it may mask producer carbon efficiencies (PCF Pilot Project Germany, 2009). Perhaps the footprint could be broken down to demonstrate the proportion of the overall emissions derived from the different phases of the life cycle (e.g., on the farm, land use change, processing, transport, and use). This may help consumers realize that even though the footprint of a particular product is relatively high, it was not the farmers in developing countries who were responsible for the majority of emissions.
6. **Encourage innovation in the food chain.** Few footprinting methods actually provide a direct incentive to the individual businesspeople in the supply chain to reduce their component of the overall carbon footprint. If footprints are presented at an aggregate level, such as when multinational companies report the footprints for their final products from a region as if it were one uniform good (e.g., sugar from Zambia, beans from Kenya, grapes from Chile), then there is little incentive for the individual businesses that contribute to the production of these products to reduce their own emissions. If individual businesses could be provided with direct incentives for reducing their emissions, then innovation in the food chain would be encouraged.
7. **Recognize that the lack of control that innovation has over carbon footprints discourages innovation.** The carbon footprints of some products of LDCs are dominated by the GHG emissions from one of two factors: land use change and/or transport by air. There is nothing that farmers and processing businesses in LDCs can do about either of these emissions. So to some extent, the impact of any innovation they make in their businesses will be inconsequential when compared to the emissions from land use change and air freight. It is important to recognize this issue and to find ways to encourage and reward even small innovations on farm that serve to reduce emissions.
8. **Develop low-cost approaches to calculation and certification.** The costs associated with the calculation and verification or certification of a carbon footprint might be prohibitive for smaller producers from less-developed countries, as is already the case for some schemes (e.g., GlobalGAP). This might lead to a situation where producers will not be able to sell to suppliers and wholesalers who demand that a carbon footprint be calculated. Small producers may be out-competed by large producers and international businesses that will find it easier to finance the cost of carbon footprinting and certification. Low-cost solutions need to be developed to help prevent this situation.

In-Country and General Development

1. **Enhance yields.** If yields of crops could be increased without increased use of inputs, and yield variability could be decreased, then the overall carbon footprint of that crop would be reduced.
2. **Encourage processing in developing countries.** If the shelf-life of a product can be extended through processing, then it may be possible to transport that product to the final market by ship instead of by air, thereby reducing emissions. Thus the processing of goods in developing countries could be encouraged, as it

may also provide economic benefits and wider carbon efficiencies, such as low capital input.

3. **Locate carbon footprints in the wider sustainability debate.** Carbon footprints are good indicators of the amount of greenhouse gases emitted during the production of a product. They are not good indicators of overall sustainable development. A more rounded picture of development could be obtained by using carbon footprints as just one of a number of indicators of wider sustainable development—for example, carbon emitted per person employed in the production phase, carbon emitted per dollar generated in households with incomes less than $50 p.a., and so forth.

Note

[1] Greenhouse gas emissions from transport are expressed as kg CO_2e/ton km. This is the total amount of greenhouse gases emitted when 1 ton of goods is transported 1 kilometer. All greenhouse gases are expressed as CO_2 equivalents, or CO_2e.

References

Aghedo, A. 2007. "A Review of African Emissions and Air Quality: The Need for a Detailed Regional Inventory." Available at www.ddrn.dk/filer/forum/File/african-emissions-and-AQM-network_2.pdf.

Althaus, H.-J., M. Chudacoff, R. Hischier, N. Jungbluth, M. Osses, and A. Primas. 2007. *Life Cycle Inventories of Chemicals.* Final report ecoinvent data v2.0. Volume 8. Swiss Centre for LCI, Empa-TSL. Dübendorf, CH.

Asda 2009. *About Asda: Energy and Carbon (Embedded Carbon).* Available at http://www.about-asda.com/sustainability/energy-carbon.asp.

Bolwig, S., and P. Gibbon 2009. "Counting Carbon in the Marketplace: Part 1—Overview Paper." Joint Working Party on Trade and Environment, Organisation for Economic Co-operation and Development, Paris.

BNDES (Banco Do Desenvolvimento de Todos Os Brasileiros). 2008. *Sugarcane-Based Bioethanol: Energy for Sustainable Development.* Rio de Janeiro: BNDES.

Bouwman, A. F., L. J. M. Boumans, and N. H. Batjes. 2002. "Emissions of N_2O and NO from Fertilized Fields: Summary Of Available Measurement Data." *Global Biogeochemical Cycles* 16: 1058.

Brenton, P., G. Edwards-Jones, and M. F. Jensen. 2009. "Carbon Labelling and Low Income Country Exports: A Review of the Development Issues." *Development Policy Review* 27: 243–265.

British Standards Institution (BSI). 2008a. *PAS 2050:2008. Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services.* London: BSI.

———. 2008b. *Guide to PAS 2050. How to Assess the Carbon Footprint of Goods and Services.* London: BSI.

Carbon Disclosure Project. 2009a. "Wal-Mart Case Study." Available at http://www.cdproject.net/wal-mart-case-study.asp.

———. 2009b. "Wal-Mart." Available at http://www.cdproject.net/wal-mart.asp.

Carbon Trust. 2008. "Energy and Carbon Conversions Fact Sheet: 2008 Update." Factsheet CTL018. Carbon Trust, London.

Edwards-Jones, G., K. Plassmann, E. H. York, B. Hounsome, D. L. Jones, and L. Milà i Canals. 2009. "Vulnerability of Exporting Nations to the Development of a Carbon Label in the United Kingdom." *Environmental Science and Policy* 12: 479–490.

Energy Information Administration. 2006. *World Net Electricity Generation by Type.* International Energy Annual 6.3.

Fischer, G., M. Shah, H. van Velthuizen, and F.O. Nachetergaele. 2001. "Global Agro-ecological Assessment for Agriculture in the 21st Century." IIASA Land-Use Change Project. IIASA, Austria.

Garnett, T. 2006. "Fruit and Vegetables and UK Greenhouse Gas Emissions: Exploring the Relationship." Working paper produced as part of the work of the Food Climate Research Network. Centre for Environmental Strategy, University of Surrey, UK.

Ikezuki, T. 2008. "Carbon Footprint Labelling Scheme in Japan." International Trade Centre, Geneva.

International Energy Agency Data Services. 2007. *CO_2 Emissions from Fuel Combustion.* Paris: OECD Publishing.

Intergovernmental Panel on Climate Change (IPCC). 2002. "IPCC Project on Establishment of a Database on GHG Emission Factors." New Delhi COP8, October 2002. Available at http://www.ipcc-nggip.iges.or.jp/EFDB/documents.php.

———. 2006a. "2006 IPCC Guidelines for National Greenhouse Gas Inventories." Prepared by the National Greenhouse Gas Inventories Programme, ed. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds). IGES, Japan.

———. 2006b. EFDB Brochure. Available at http://www.ipcc-nggip.iges.or.jp/support/EFDB_Brochure.pdf.

IPCC-EFDB. 2009. "Database on Greenhouse Gas Emission Factors." Available at http://www.ipcc-nggip.iges.or.jp/EFDB/main.php.

Jones, A. 2006. "A Life Cycle Analysis of UK Supermarket Imported Green Beans from Kenya." International Institute for Environment and Development, London.

Milà i Canals, L., I. Muñoz, A. Hospido, K. Plassmann, and S. McLaren. 2008. "Life Cycle Assessment (LCA) of Domestic vs. Imported Vegetables: Case Studies on Broccoli, Salad Crops and Green Beans". Working Paper 01/08. Centre for Environmental Strategy, University of Surrey, UK.

Mosier, A. R., J. M. Duxbury, J. R. Freney, O. Heinemeyer, and K. Minami. (2004. "Assessing and Mitigating N_2O Emissions from Agricultural Soils." *Climatic Change* 40: 7–38.

"National Greenhouse Gas Inventories." 2009. UK, Norway, United States, Australia, New Zealand. Available at http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/4771.php.

Nayamuth, A. R. H., and B. F. Cheeroo-Nayamuth. 2005. "Contribution of the Sugarcane Industry in Alleviating Greenhouse Gas Emissions." *Proceedings of the International Society of Sugar Cane Technologists* 25: 57–62.

Nemecek, T., T. Kägi, and S. Blaser. 2007. "Life Cycle Inventories of Agricultural Production Systems." Ecoinvent report version 2.0, Volume 15. Swiss Centre for LCI, ART. Dübendorf and Zurich, CH.

PCF Pilot Project Germany. 2009. "Product Carbon Footprinting: The Right Way to Promote Low Carbon Products and Consumption Habits? Experiences, Findings and Recommendations from the Product Carbon Footprinting Pilot Project Germany." PCF Pilot Project Germany, Berlin.

Ramjeawon, T. 2004. "Life Cycle Assessment of Cane Sugar on the Island of Mauritius." *International Journal of Life Cycle Assessment* 4: 254-260

Renewable Fuels Agency. 2008. *Carbon and Sustainability Reporting within the Renewable Transport Fuel Obligation.* Table 5, Technical Guidance Part Two, Version 1.3.

Centre for Sustainability and the Global Environment (SAGE). 2000. "Global Land Use Data, Land Suitability for Cultivation, by AEZ." Available at http://www.sage.wisc.edu/iamdata/units.php.

Sanjuán, N., L. Úbeda, G. Clemente, A. Mulet, and F. Girona. 2005. "LCA of Integrated Orange Production in the Comunidad Valenciana (Spain)." *International Journal of Agricultural Resources, Governance and Ecology* 4: 163–177.

Soil & More International. 2008a. "Full Product-Cycle Carbon Footprint Calculation for Organic Certified Kiwis from Freshco Farms, New Zealand via EOSTA BV, Netherlands to Its European Retail Customers: A Study Carried Out by Soil & More International BV for EOSTA BV."

———. 2008b. "Full Product-Cycle Carbon Footprint Calculation for Organic Certified Citrus (Oranges And Grapefruits) from the Groenheuwel Farms, South Africa via EOSTA BV, Netherlands to Its European Retail Customers: A Study Carried Out by Soil & More International BV for EOSTA BV."

Spielmann, M., R. Dones, and C. Bauer. 2007. "Life Cycle Inventories of Transport Services." Final report ecoinvent Data v2.0, Volume 14. Swiss Centre for LCI, PSI. Dübendorf and Villigen, CH.

Stehfest, E., and L. Bouwman. 2006. "N_2O and NO Emission from Agricultural Fields and Soils under Natural Vegetation: Summarizing Available Measurement Data and Modeling of Global Annual Emissions." *Nutrient Cycling in Agroecosystems* 74: 207–228.

Stratmann, B., J. Teufel, and K. Wiegmann. 2008. *Umweltauswirkungen von Ernährungsgewohnheiten.* Öko-Institut e.V., Freiburg, Germany.

Wal-Mart Stores Inc. 2009a. "Carbon Disclosure Project." Available at http://walmartstores.com/Sustainability/7759.aspx?p=8141.

———. 2009b "Reducing Carbon in our Supply Chain." Available at http://walmartstores.com/sites/sustainabilityreport/2009/en_c_redCarbon.html.

Weidema, B. P., R. L. Pedersen, and T. S. Drivsholm. 1995. *Life Cycle Screening of Food Products.* Danish Academy of Technical Sciences.

Williams, A. G., E. Audsley, and D. L. Sandars. 2006. "Determining the Environmental Burdens and Resource Use in the Production of Agricultural and Horticultural Commodities: Main Report." Defra Research Project IS0205. Bedford, MA: Cranfield University and Defra.

Eco-Audit

Environmental Benefits Statement

The World Bank is committed to preserving Endangered Forests and natural resources. We print World Bank Working Papers and Country Studies on postconsumer recycled paper, processed chlorine free. The World Bank has formally agreed to follow the recommended standards for paper usage set by Green Press Initiative—a nonprofit program supporting publishers in using fiber that is not sourced from Endangered Forests. For more information, visit www.greenpressinitiative.org.

In 2008, the printing of these books on recycled paper saved the following:

Trees*	Solid Waste	Water	Net Greenhouse Gases	Total Energy
289	8,011	131,944	27,396	92 mil.
*40 feet in height and 6–8 inches in diameter	Pounds	Gallons	Pounds CO_2 Equivalent	BTUs

green press INITIATIVE

Carbon Footprints and Food Systems is part of the World Bank Studies series. These papers are published to communicate the results of the Bank's ongoing research and to stimulate public discussion.

Carbon accounting and labeling instruments are designed to present information on greenhouse gas emissions from supply chains and are important in raising awareness for governments, producers, retailers, and consumers. This paper analyzes current carbon accounting methodologies for sugar and pineapple products from Zambia and Mauritius, compares different carbon accounting and labeling schemes to assess their potential for accurately representing productions systems in developing countries, and concludes with a series of recommendations to inform the public on how carbon labeling and accounting can be more development-friendly.

World Bank Studies are available individually or on standing order. This World Bank Study series is also available online through the World Bank e-library (www.worldbank.org/newelibrary).

ISBN 978-0-8213-8539-5

SKU 18539

THE WORLD BANK