Food and Agriculture
Organization of the
United Nations

ECUADOR'S BANANA SECTOR UNDER CLIMATE CHANGE

An economic and biophysical assessment to promote a sustainable and climate-compatible strategy

ECUADOR'S BANANA SECTOR UNDER CLIMATE CHANGE

An economic and biophysical assessment to promote a sustainable and climate-compatible strategy

Edited by
Aziz Elbehri

Lead authors
Aziz Elbehri; Germán Calberto; Charles Staver,
Almudena Hospido; David Skully

Contributing authors
Laura Roibás; Pablo Siles; Jessenia Arguello;
Ignacio Sotomayor; Antonio Bustamante

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
ROME, 2016

Required citation:

FAO, 2016. Ecuador's banana sector under climate change: An economic and biophysical assessment to promote a sustainable and climate-compatible strategy, by Elbehri, A., G. Calberto, C. Staver, A. Hospido, L. Roibas, D. Skully, P. Siles, J. Arguello, I. Sotomayor and A. Bustamante. Rome, Italy.

The designations employed and the presentation of material in this information product do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations (FAO) concerning the legal or development status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. The mention of specific companies or products of manufacturers, whether or not these have been patented, does not imply that these have been endorsed or recommended by FAO in preference to others of a similar nature that are not mentioned.

The views expressed in this information product are those of the author(s) and do not necessarily reflect the views or policies of FAO.

ISBN 978-92-5-109249-1

© FAO, 2016

FAO encourages the use, reproduction and dissemination of material in this information product. Except where otherwise indicated, material may be copied, downloaded and printed for private study, research and teaching purposes, or for use in non-commercial products or services, provided that appropriate acknowledgement of FAO as the source and copyright holder is given and that FAO's endorsement of users' views, products or services is not implied in any way.

All requests for translation and adaptation rights, and for resale and other commercial use rights should be made via www.fao.org/contact-us/licence-request or addressed to copyright@fao.org.

FAO information products are available on the FAO website (www.fao.org/publications) and can be purchased through publications-sales@fao.org.

© Photo credits:
Cover photo: ©/FAO Aziz ElBehri

Contents

CHAPTER 4: ASSESSMENT OF CLIMATE CHANGE IMPACT ON BANANA PRODUCTION AND SUITABILITY IN ECUADOR, AND GENERAL ASSESSMENT OF GLOBAL BANANA TRENDS UNDER CLIMATE CHANGE SCENARIOS 63

LIST OF TABLES

LIST OF FIGURES

Preface and acknowledgements

Ecuador's banana sector is crucial for the national economy, employment and the country trade balance. Both the economic, social and environmental implications of banana value chains challenges present policy choices and trade-offs in Ecuador. Raising productivity of the sector, improving fair distribution of value added among the private actors (workers, farmers and exporters), and enhancing sustainable phytosanitary practices top the Government priorities. On top of this, climate change is raising additional concerns over the long term viability and suitability of banana in Ecuador. The climate change challenge is multifaceted manifested through reduced water availability from declining Andean glaciers, changing rainfall patterns to rising temperatures and consequent potential increasing of disease incidences and or severity.

At the request of the Ecuadorian Government, FAO undertook a technical assistance project providing an assessment of climate change impacts on the banana value chain in support of the Ecuador initiatives towards sustainable and climate-adapted strategies. The sectorial assessment covered both biophysical and socio-economic analyses following an integrated framework devised specifically for sector or market level analysis of climate change impacts in agriculture. The integrated assessment framework was applied in other countries and crops (Tea in Kenya and fruit trees in Morocco). The biophysical analysis included: (i) an evaluation of banana suitability under climate change in Ecuador and elsewhere; (ii) climate change impacts on yields and diseases incidence; (iii) quantifying carbon footprint and GHG emissions associated with banana production, including the stages from transportation to consumption. The socio-economic analysis examined the national social policies to ensure a fairer distribution of returns to stakeholders across the banana value chain, especially with regard to smallholder farmers and banana plantation workers, who play an important role as constituents within Ecuador's main agricultural industry. The analysis also covered the issue of governance, relating to the banana value chain within Ecuador (labourers, producers, exporters) and beyond (consumers). These studies were carried between September 2012 and December 2013. The findings of these studies were presented at a national multi-stakeholder workshop held in January 2014 in Guayaquil, Ecuador.

The project was carried out under the overall technical supervision of Aziz Elbehri, Senior Economist from FAO's Trade and Markets Division and the field supervision of Mr. Pedro Pablo Pena, FAO representative of Ecuador. In-country and field work coordination was carried out with the active interventions of Mr Jorge Samaniego and Ms. Maria Jose Alvear from the FAO Office in Quito and by Aicha Dellero, from FAO HQ. For the normative analyses, FAO mobilized a team of FAO and international experts, supported by two national consultants: Mr Gustavo Novillo, and Mr Trossky Maldonado. The successful completion of the sectorial assessment was made possible because of the strong commitment and helpful assistance received from the national partners and their representatives who exhibited a high degree of enthusiasm and interest in FAO's work. Special recognition for valuable assistance throughout the project goes to Ms. Lisseth Moreira, Director of International Cooperation within the Ministry of Agriculture; Mr. Marco Antonio Oviedo Cajas, focal point for the Project from the Ministry of Agriculture; and Mr. Ignacio Sotomayor from INIAP – National Agricultural Research Institute.

This report is divided into 6 chapters. Chapter 1 (Aziz Elbehri) describes the overall conceptual framework that guided the project. Chapter 2 (Aziz Elbehri), reports on the economic and policy analysis of the banana value chain in Ecuador and the implications for social, environmental sustainability. Chapter 3 (David Skully and Aziz Elbehri) provides an overview of the specific climate change issues likely to face Ecuador and the banana industry. Chapter 4 (German Calberto and colleagues) is an in-depth quantitative analysis of the banana suitability in Ecuador under climate change carried out by a team of researchers from Diversity International led by Charles Staver. Chapter 5 (Almudena Hospido and Laura Roibas) provides a new life cycle/carbon footprint analysis on banana in Ecuador. Chapter 6 (David Skully) provides an economic analysis of carbon policy and its impacts on banana demand, supply and trade.

Funding for the project was provided through FAO's Multidonor Mechanism with financial support from the Swedish International Development Cooperation Agency.

Administrative support was carried out by Nadia Laouini and Patricia Taylor from FAO Trade and Markets Division. Supplemental technical assistance and literature review was provided by Pedro Soussa. The manuscript was copy edited by Margie Peters-Fawcett while art design and final formatting was provided by Rita Ashton and Ettore Vecchione.

Abbreviations and acronyms

AET	actual evapotranspiration
BS	Black Sigatoka
CO^2	carbon dioxide
°C	degree Centigrade
CBI	Chiquita Banana, Inc.
CCAFS	Climate Change, Agriculture and Food Security
CRU	Climate Research Unit (University of East Anglia, UK)
ENSO	El Niño Southern Oscillation
ERain	effective rainfall
ET	evapotranspiration
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Statistics Division of the FAO
FOB	free on board
GHG	Greenhouse gas
GMP	Green Morocco Plan
GNP	gross national product
GDD	growing degree days
GSP	Generalized System of Preferences
ha	hectare
ILCYM	Insect Life Cycle Modeling
IMO	International Maritime Organization
INAMHI	National Institute of Meteorology and Hydrology
INIAP	Instituto Nacional Autónomo de Investigaciones Agropecuarias
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
kg	Kilo, kilogram
km	kilometre
kWh	kilowatt hour

LCA	life cycle analysis
m	metre
MAGAP	Ministry of Agriculture and Livestock
mm	millimetre
MNC	multinational corporations
MT/ha	metric tonnes per hectare
N	nitrogen
N_2O	nitrous oxide
NGO	nongovernmental organization
PET	potential evapotranspiration
RDC	regional distribution centre
SCC	social cost of CO_2
TDU	thermal development units
TEU	20-foot equivalent value


©FAO/Aziz Elbehri

CHAPTER 1:

OVERVIEW: A METHODOLOGICAL FRAMEWORK - INTEGRATING CLIMATE ADAPTATION AND SUSTAINABILITY INTO AGRICULTURAL SECTORS

Aziz Elbehri *

---

* Trade and Markets Division, Department of Economic and Social Development, Food and Agriculture Organization of the United Nations (FAO), Rome

1. Introduction

Climate change is expeted to exacerbate the sustainability of most agricultural systems and threaten long-term agricultural productivity, food supply, and future food security. Tackling the impacts of climate change and ensuring that agriculture is aligned with climate-compatible practices is of the utmost urgency. Concerted efforts at the farm, national, regional and global levels are necessary to deploy a variety of solutions, interventions and instruments to address the impacts of climate change on agriculture. Climate adaptation in agriculture should be viewed in broad terms and should proceed beyond the scope of current agricultural techniques. Adaptation to changing conditions is a dynamic process and should not be viewed as a temporary measure, nor should adaptation be reduced to new agricultural techniques. It must also cover institutional reform, policy and regulatory instruments, as well as harness market-based mechanisms.

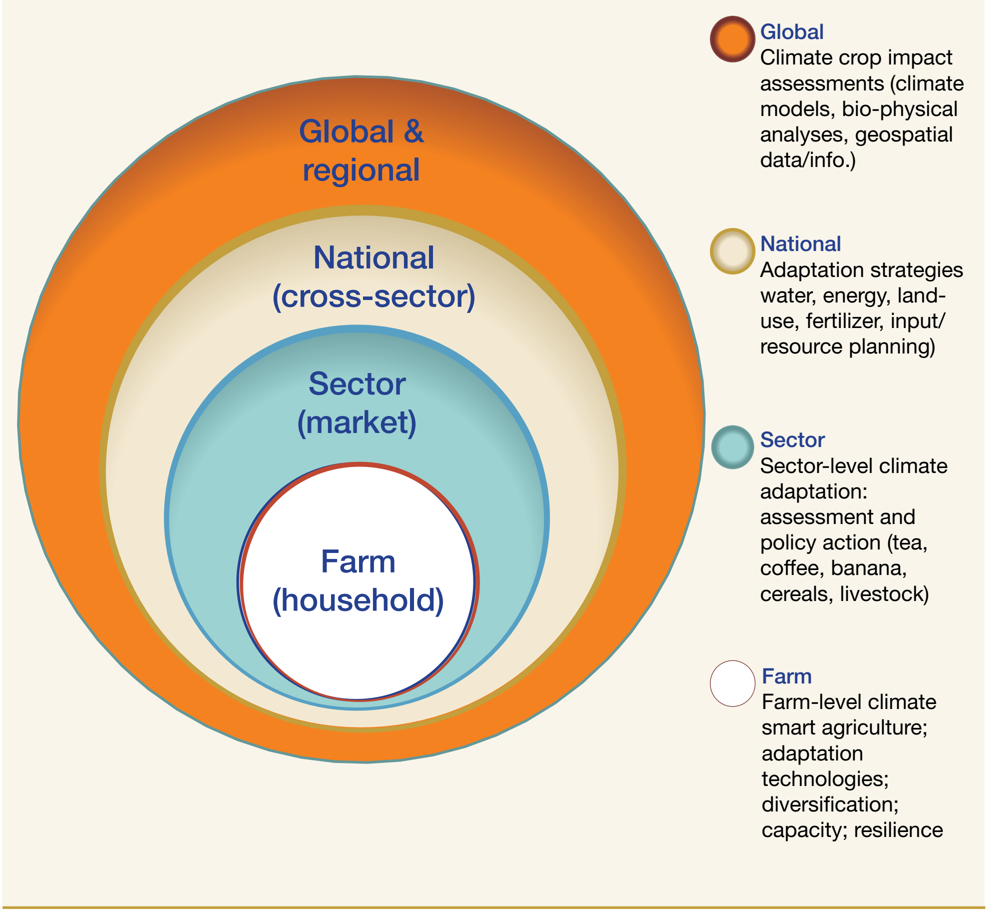
Action on climate change in agriculture requires a multitude of measures; innovative approaches to adaptation and mitigation; and integrated policies and strategies. A systems approach that can link climate change to sustainable agricultural development is essential for an effective transition to climate-smart agriculture, where adaptation and mitigation are integrated into sustainable agricultural intensification. An effective climate action must derive from evidence-based assessments to inform policy-making and to propose concrete and context-relevant options and interventions. Planning, assessments, and interventions are likely to come at various scales, ranging from the global to the farm level. Climate-smart agriculture policy formulation also requires a dynamic and greater degree of coordination by stakeholders and policy-makers alike.

2. Climate impact analysis for agriculture: The question of scale

Given the specific nature of agricultural systems, the selection of scale for analysis and climate action is a critical first step towards a decision which will depend on the targeted objective. Figure 1 shows the four key scales to consider for climate impact assessment and policy action.

At the **global** level, the focus of climate action is to evaluate the broad trends in agricultural productivity impacts, resource availability and future land use, as well as the likely impacts of climate change and their relative magnitude. Assessments at this scale rely on global aggregate climate, crop and economic models that use data on climate, biophysical and socioeconomic trends. The aim is to derive the relative magnitude of changes across regions and agricultural systems. Global models - such as the Global Agro-Ecological Zones (developed by the Food and Agriculture Organization (FAO) and the International Institute for Applied Systems Analysis) and the Agricultural Model Inter-Comparison and Improvement Project model suite - have been applied to estimate the magnitude of climate change impact on future productivity trends for major crops, animal systems, forestry and fisheries. These global assessments provide the evidence used within the global governance framework of the United Nations

Figure 1 The four scales of climate impact analysis and action



Global
Climate crop impact assessments (climate models, bio-physical analyses, geospatial data/info.)

National
Adaptation strategies water, energy, land-use, fertilizer, input/ resource planning)

Sector
Sector-level climate adaptation: assessment and policy action (tea, coffee, banana, cereals, livestock)

Farm
Farm-level climate smart agriculture; adaptation technologies; diversification; capacity; resilience

Source: A. Elbehri

Framework Convention on Climate Change, which seeks to reach common agreement across countries for joint action, the mobilization of resources and the development of the global governance that is essential to implement adaptation and mitigation actions.

At the **regional** level - and within homogenous and contiguous regions - the aim is to evaluate the common threads, challenges and issues relating to climate change and its impact on regional agriculture, resources (soils, water) and food security. Analyses may combine both regionally and locally specific models to generate the evidence required for joint policy action. Setting a common strategy; sharing best practices with regard to policy and interventions; and seeking economic integration, including through the enhancement of regional trade, will require increased regional coordination. In addition, it is essential to establish regional institutions to monitor, manage and share information to improve the efficiency in the use of resources (e.g. water) and to implement national adaptation plans. At this scale, efficient management of critical resources, such as water, or combating other climate-induced threads to agriculture are examples of climate-compliant interventions that should be jointly pursued.

At the **national** level, climate adaptation for agriculture begins with macro-policies, regulations and institutional reform. Emphasis is placed on adaptation strategies for cross-cutting sectors, such as energy, water and infrastructure. Decisions for agricultural adaptation focus on cross-sectoral investments in research, infrastructure (i.e. irrigation) and rural financial services (banking). The implementation of national adaptation plans also will necessitate a heightened degree of coordination across sectors, institutional reforms and improved governance structures in order for multilayered adaptation decisions to take place, aimed at transitioning towards climate-smart agriculture.

Concrete planning, assessments and proposals for action, however, can best be done at the sub-**sector** level (e.g. crops, livestock, agro-forestry), agro-ecologically or territorially. Designing a climate-smart, sector-level strategy requires a systems analysis that will include the economics of the sector, the biophysical implications of climate impacts, and the socio-institutional aspects that include governance and gender dimensions. A biophysical analysis of the sector will identify the sector's vulnerable areas vis-a-vis climate change in terms of yields, disease and resource availability. The economics of the sector will cover the policy and regulatory environment, market structure, drivers of demand and supply (including trade) and sector competitiveness, as well as the level of efficiency of resource use and the likely evolution under climate change. A socio-institutional analysis will generate an understanding of the scope to improve stakeholder participation in the decision-making (governance) process and the scope to leverage the economic and regulatory incentives by decision-makers. A sector/territorial level assessment is the appropriate scale to develop a precise action plan that will be supported by an investment programme; institutional reforms; agricultural research and extension; market-level regulations; trade and other economic incentives to induce farmers, forestry folk and fishermen to adopt climate-compatible technologies and practices. The sector/territorial level analysis of climate smart-agriculture is a necessary bridge between national cross-sectoral policy interventions and farm-level adaptation decisions.

At the **farm** level, adaptation decisions are made on the basis of internal endowments and constraints, as well as external incentives. Farms and households have internal resources to cope with a changing climate and to adapt accordingly. These include changing crop patterns, adopting new production techniques, and reallocating labour to other uses, such as outside agriculture. Farms may also exhibit limits to adaptation, owing to a lack of - or dwindling - resources (water), information, credit or a combination of the three. Smallholder farmers often face more constraints to adapt than do the larger farms. Farms also respond to external signals or incentives to change practices to improve productivity and resilience. Analysing the internal and external factors that influence the decision of farmers to adapt is an important step. It is, however, insufficient. It will need to be complemented with a sector- or territory-wide analysis to identify and recommend the macro- or sector-wide incentives and measures to motivate farmers to change their practices and shift towards a more climate-compatible agriculture.

Each of the above scales is essential at some level within the process towards action, but none is adequate on its own. It will involve an integrated approach, possibly combining at least two or more scales. An analysis at the farm level requires a parallel sector/market assessment to deduce the critical macro-economic incentives (e.g. prices, supply and demand factors, trade, sector-wide regulations) to understand how best to prompt a transition to climate-smart practices within the sector or territory. Similarly, a sector assessment should be complemented with a national and cross-sectoral analysis to align the sector-specific process with relevant national policies, institutions and resource management and investment decisions. Solutions at the sectoral level will identify the links between evidence and policy-making which, in turn, can guide the formulation of interventions or strategies at the national or cross-sectoral level. National policies for food security and climate adaptation and mitigation also can be facilitated under a regional strategic framework to tackle the common challenges and objectives.

3. A sector-specific framework for climate adaptation

This section describes a methodological framework to assess the climate impact on agriculture and to facilitate policy action at the sector/territory level. This framework has been applied with success in relation to Kenya's tea sector, Ecuador's banana sector and Morocco's fruit tree sector. In all cases, the objective is to undertake an inter-disciplinary climate impact assessment (economic, biophysical and socio-institutional) and apply the evidence to initiate a stakeholder-led process towards a climate-compatible sector strategy or improve policy implementation. The experiences of these countries have confirmed the suitability of the demand-centred approach that focuses on a strategic sector. In Kenya, a new climate-compatible strategy for tea was developed and a new policy reform for tea initiated. In Ecuador, evidence from banana interventions has encouraged the Government of Ecuador to press for environmentally sound disease controls. It also has encouraged work to be done with regard to adaptation best practices as part of the productivity-boosting efforts under Ecuador's existing Banana Law. In Morocco, the evidence has contributed to mainstreaming innovative adaptation tools within the Plan Maroc Vert - a national investment program for agricultural intensification and value addition.

3.1 Framework overview

To integrate climate adaptation and sustainability into agriculture, a sector-level approach is needed, as well as an appropriate framework that can effectively tackle the economic, social and environmental dimensions in a coherent, complementary and interlinked manner. To effectively evaluate the scope for climate adaptation and enhance the sustainability of a particular agricultural system, an economic analysis should be made to clearly separate the characteristics that drive efficiency from those that contribute to the lack of sustainability. The analysis should include the key aspects of the market, institutions and governance.

Subsequently, a biophysical assessment of the agricultural system should be undertaken, taking into account the agronomic, agro-ecological and geospatial (or territory) considerations relating to the evaluation of the likely impacts of climate change and the scope for adaptation. The economic and biophysical assessments will identify the existing sources of unsustainability and the economic incentives and disincentives that drive them. Such an assessment will establish the technical options available in terms of adaptation, as well as the economic incentives that are essential. To transition to a more sustainable agricultural system, however, a socio-institutional analysis will be required in order to address the critical issue of governance so as to ensure social acceptance and inclusive policy-making by stakeholders at the national, sector and farm levels. This will pinpoint the critical sources of vulnerability and will identify possible solutions to develop appropriate policies and implementation strategies.

3.2 Description of proposed framework

The proposed framework includes specific agriculture sub-sectors (e.g. crop-based, livestock, mixed, agroforestry or a geospacial ecosystem) that share a common set of biophysical and socio-institutional analyses that will focus on the sustainability implications of the system and the exacerbating impacts of climate change. The aim of the analysis is to identify the scope of climate adaptation and enhance resilience, while ensuring continuous economic viability and social equity (Figure 2). To enable a transition to a climate-compatible (sometimes referred as climate-smart agriculture), the framework is implemented in three stages. Figure 3 illustrates this.

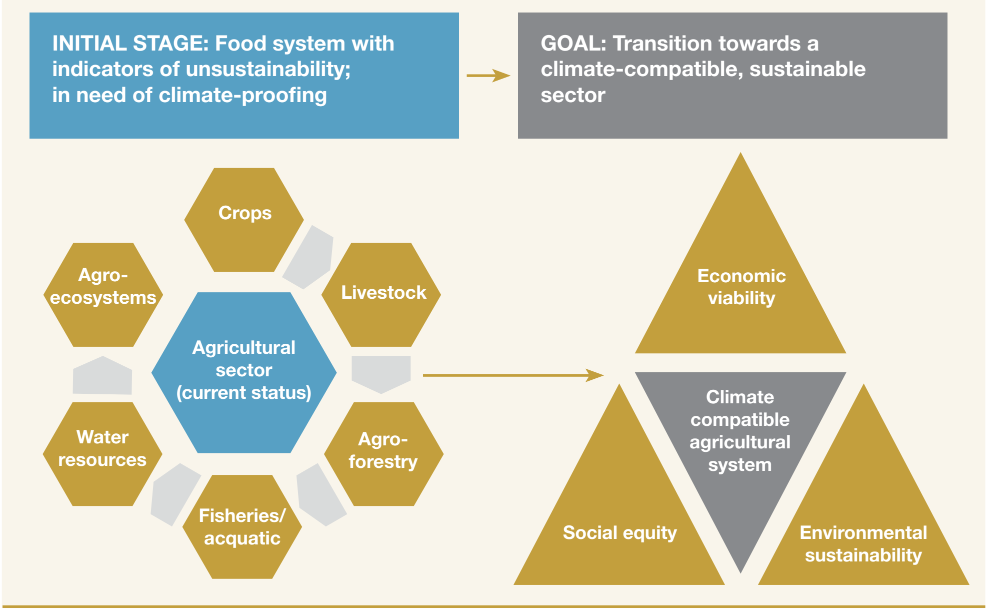
4. Stage 1: Tri-dimensional analytical

This stage includes the gathering of evidence. The framework is schematically described in Figure 4.

4.1 Economic analysis

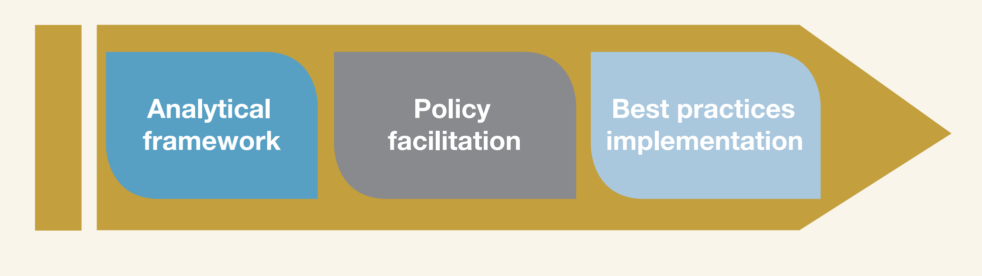
The economic analysis should include an appraisal of the production, productivity and extent of input use (intensification). Agronomy and agro-ecology are determining factors as are the economic drivers (incentives and disincentives). The focus of the economic analysis should be twofold: an appraisal of the (i) economic efficiency and its drivers, including the sources of comparative advantage, and (ii) negative externalities that contribute to the current state of unsustainability of the system. This can be linked to the presence of incentives in overuse input resources that lead to the sub-optimal use of resources or economic disincentives to resource preservation. This, in turn, should lead to an appraisal of the negative externalities that are linked to the agricultural system, defined by its agronomic and agro-ecological factors, as well as to the set of economic incentives and disincentives that drive the production process.

Figure 2 Problem statement: from unsustainable to a climate-compatible sector



Source: A. Elbehri

Figure 3 Three-stage approach to sector-level climate adaptation



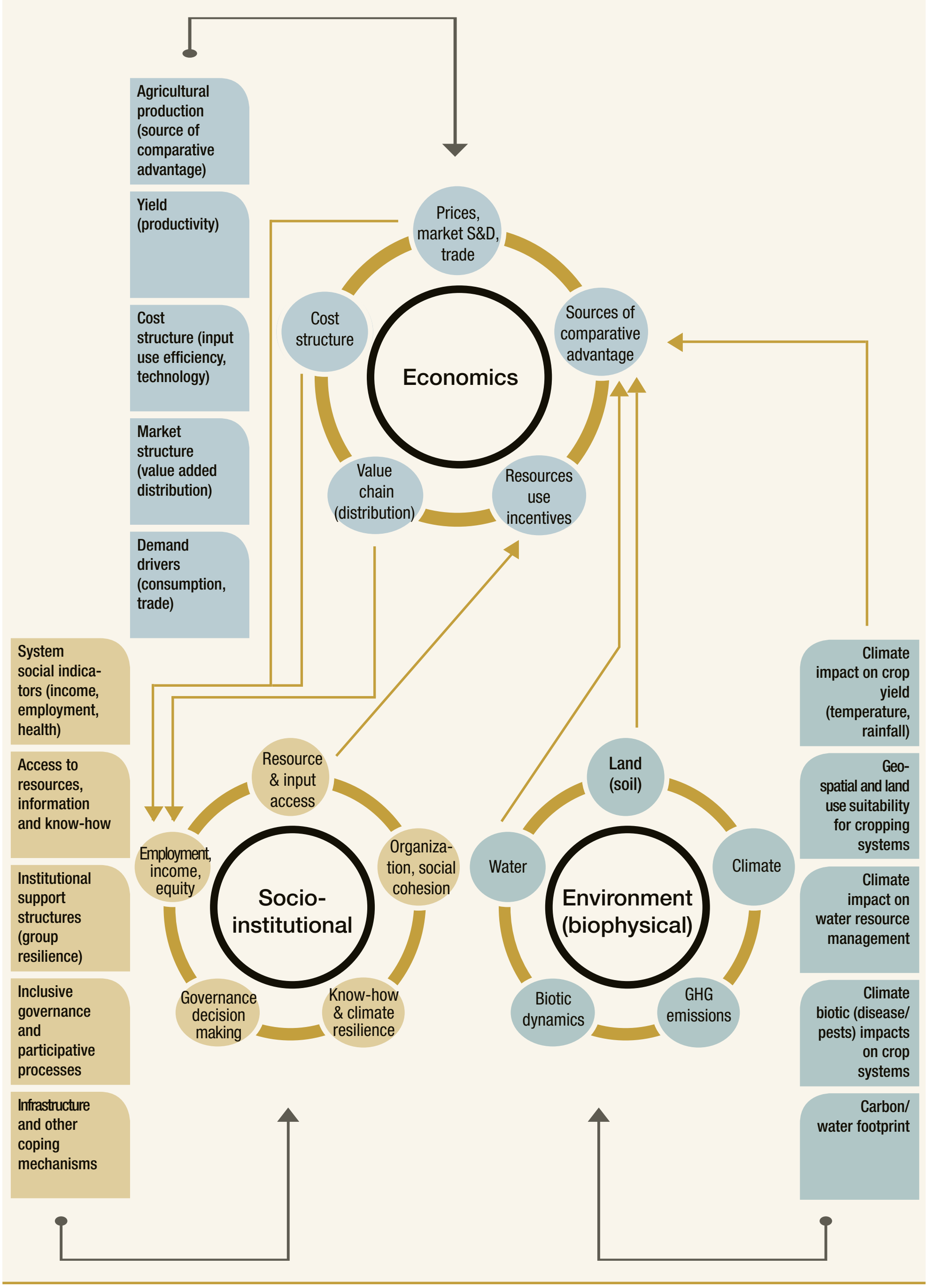
Source: A. Elbehri

Finally, the economic analysis should provide the basis for determining the scope to adjust the economic levers that are necessary to tackle the current unsustainability constraints and future challenges arising from changing climate.

4.2 Biophysical analysis

The biophysical analysis of the agriculture sector should cover the climate impact assessment of the specific crop and it should draw from existing analyses at various levels (national, regional, and local). Ideally, such an analysis would use

Figure 4 Tri-dimensional conceptual framework for sector-level climate adaptation analysis



Source: A. Elbehri

locally available changing climate parameters that apply, as much as possible, to the crop that is analysed. The focus of this climate impact assessment will be dictated as much by the regional location of the agricultural system as by the agronomy and the agro-ecology of the crop. The biophysical analysis may also stress specific issues that are critical to the production system, such as water hydrology (in terms of future water demand and supply) and/or land classification. When relevant, the analysis also may emphasize the biotic dynamics of climate change on the crop, especially in those situations where pests and disease are important features of the cropping system or where the changing climate is thought to introduce new biotic dynamics in the future, which will alter the management and the productivity of the system.

Finally, the biophysical analysis of the agricultural system should include an environmental assessment that includes the carbon cycle and carbon footprint of the current production system and the implications for greenhouse gas (GHG) emissions for mitigation. It is important to recognize that the specific focus of the biophysical analysis should be dictated by the local climate, the crop agronomy and the associated management system, as well as by the location agro-ecology, including the biotic and abiotic aspects. Existing cropping systems and management (the latter of which is tied to economics) are as much factors as are those of pure environmental and ecological considerations.

4.3 Socio-institutional analysis

Adaptation options can be technically possible and economically viable; however, they still need to be socially feasible and acceptable. The socio-institutional analysis is the critical third dimension that assures the link to policy processes. It is, however, highly context-specific. The economic analysis of the agricultural system already will offer pointers to the critical dimensions for focus. Cost analysis and value distribution will suggest the social implications of the economic systems with regard to the return to labour, employment and incomes. Management systems also will highlight the social issues relating to input access, the role of gender and the significance of youth in the production system. Land and water considerations, which are inputs into the economic analysis, will have social implications in terms of access, management and investments. In examining the scope for adaptation and building resilience, a review of social coherence, modes of decision-making and organization structures is important to factor in.

Lastly, an analysis of the enabling environment should be made in terms of infrastructure, investments and capacity. This will require an evaluation of governance systems, participatory processes and the extent of inclusive decision-making in order to facilitate the adaptation of improved techniques to enhance productivity, as well as climate-adaptation and emissions saving when relevant. To the extent that adaptation strategies and policies are introduced or facilitated, adaptation technologies will require greater adherence by men and women farmers - the ultimate decision-makers. This will require a thorough socio-institutional analysis of the agricultural system within the local physical, economic and institutional environments.

4.4 Interlinkage of the three dimensions

While each of the three main analyses (economic, biophysical and socio-institutional) have a core set of issues to be examined in relation to the sector under examination, there are important linkages that cut across the three dimensions and serve as feeding loops. For example, a biophysical analysis of the impact of climate change on water, temperature and soil conditions (biophysical) directly feeds into resource use, affecting economic input use efficiency which, in turn, will affect the cost structure (economic) and which, ultimately, will affect the return to labour and incomes (social). Likewise, when climate change is expected to reduce water availability, this will in turn change the economics of the agricultural system (through productivity, water efficiency and related cost), which may require policy decisions for water resource management and reallocation across uses (social).

Another example is when climate change (through temperature and rainfall changes) alters the dynamics of pests (biophysical), thus altering the productivity of the system. This, in turn will change the input use intensity and, hence, the cost-benefit structure (economic) with social implications in terms of income and health (chemical and pesticide use). It will also implicate policy and governance (socio-institutional). Clearly, the identification of the linkage between the three dimensions is critical for a coherent and interconnected assessment. It is necessary to provide the evidence upon which an adaptation strategy can be built upon.

There are two key prerequisites for the successful implementation of this analytical framework. First, it is necessary to have as much local expertise as possible at all levels and at all times. Second, it is critical to make use of available local data, information and knowledge. These not only will ensure more relevant outcomes but they will facilitate local ownership of the process - essential to ultimately enact and achieve transformation. This may not always proceed smoothly in the context of developing countries, however, where data is often not available or is not easily accessible or usable. Moreover, national research data may often be lacking, which will necessitate capacity building from external sources. The two mentioned prerequisites, however, are important and should be followed whenever possible.

5. Stage 2: Policy formulation

The above description of the proposed analytical framework provides the evidence that is necessary to initiate the second stage (policy formulation). This, by definition, is a process that should be led by multistakeholders to focus on the issues and frame them by using the insights and evidence obtained from the initial analyses. Attention should be placed on identifying and introducing a climate-compatible strategy or policy that is tailored to the agricultural sector under evaluation, but which is in line with a broader national policy and cross-sectoral climate change strategy. The process of climate adaptation also requires synergies that are horizontal (across ministries and government agencies) and vertical (between public and private sectors, especially between government and vulnerable stakeholders, including small-scale farmers, women and young groups).

6. Stage 3: Adaptation strategy implementation

This stage involves investment strategy and economic incentives. These will encourage the uptake of adaptation best practices, institutional reforms, and a transition to governance structures that are necessary to achieve climate adaptation and sustainability.

7. Application to three agricultural systems: Kenya, Morocco, and Ecuador

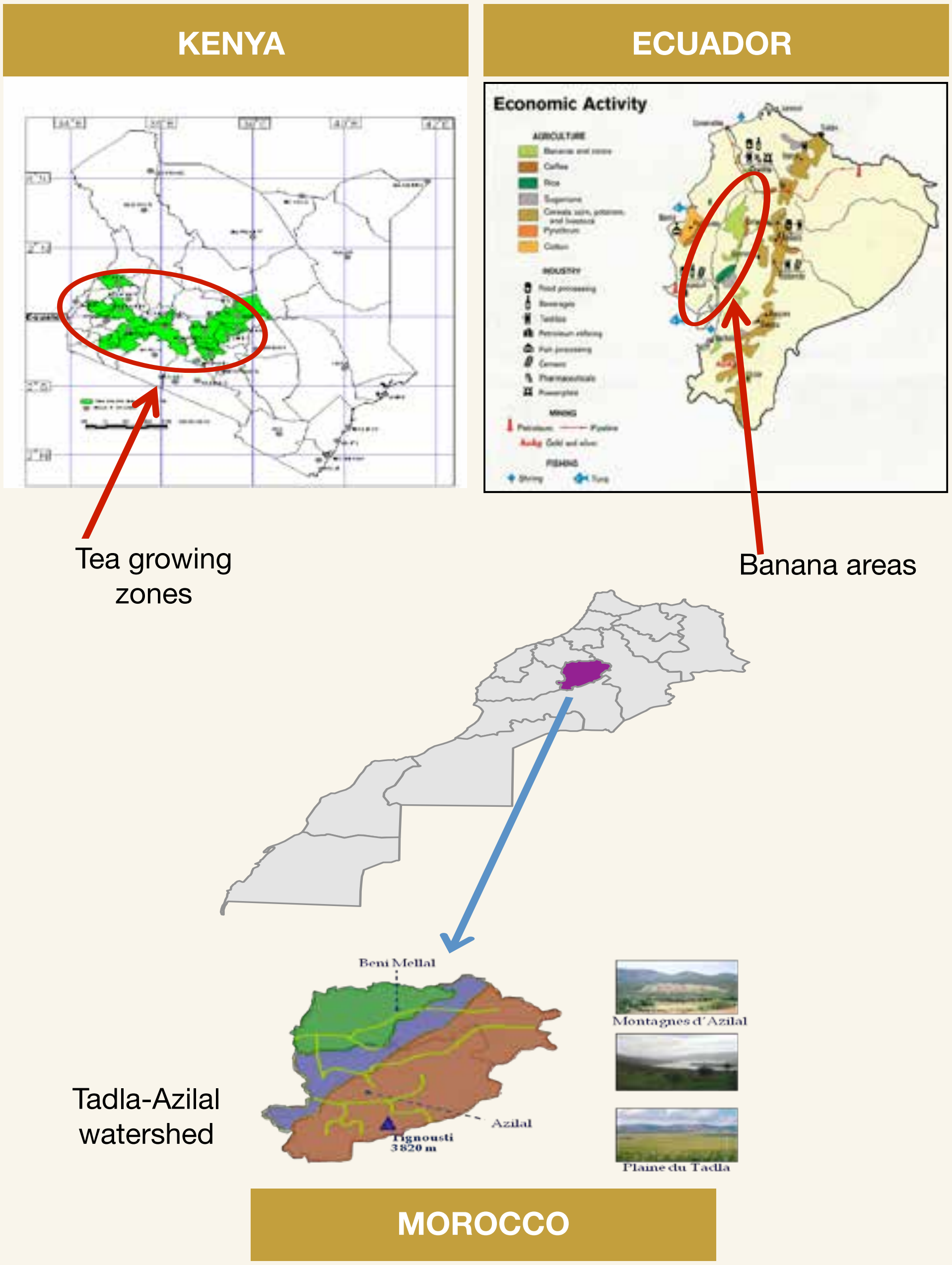
The conceptual framework described in this section was applied in three countries under three FAO pilot projects relating to the (a) banana value chain in Ecuador; (ii) tea sector in Kenya; and (iii) fruit tree crops in Morocco (Figure 5). Each pilot project included a full-scale climate adaptation assessment, followed by a participatory policy process that involved sectoral and national government stakeholders.

7.1 Kenya's tea sector: Developing an evidence-based climate-smart strategy

FAO's intervention in Kenya included an impact assessment of the tea sector with respect to climate change. Tea is the country's principal agricultural industry, employing over 2 million people. A two-stage approach was applied, spearheaded by a multidisciplinary impact assessment and followed by a multistakeholder and inclusive process, through which a new climate-smart strategy for tea was developed for Kenya. The multidisciplinary framework included a biophysical study of the link between climate and tea yields, a life-cycle analysis of tea, and a crop modeling of tea management under various climate scenarios (Aquacrop model). The economic analysis of the tea value chain in Kenya included a market analysis; sources of productivity and comparative advantages; a cost structure; the continued supply of improved varieties; and techniques that have increased production and ensured that Kenya is the world's leading tea producing country.

Once the cumulative evidence was obtained from the studies, a multistakeholder process was initiated to develop a climate-compatible strategy for Kenya's tea sector. A national dissemination workshop, attended by representatives of government agencies, private industry and civil society, was organized where the study findings were shared and discussed. This was followed by a Technical Committee meeting, facilitated by FAO and representing relevant stakeholders to discuss the role of collectively developing a new climate-adaption tea strategy for Kenya. The Committee included representatives from Kenya's Ministry of Agriculture (Climate Change Unit), Ministry of Environment (Climate Change Secretariat), National Environment

Figure 5 Application of the multidisciplinary framework for climate adaptation in Ecuador, Kenya and Morocco



Source: A. Elbehri

Management Authority, Tea Board of Kenya, Tea Research Foundation of Kenya, Kenya Tea Development Agency Ltd., as well as representatives of large tea plantations, members of the Kenya Tea Growers Association, Kenya Meteorological Department and Kenya Institute for Public Policy Research and Analysis, among others.

7.2 Morocco's fruit tree crops: mainstreaming climate adaptation within the Green Morocco Plan

In the case of Morocco, FAO's pilot project aims to develop the methodology and tools necessary to mainstream climate adaptation for small-scale agriculture relating to Morocco's fruit tree crops, especially within its agricultural investment programme: the Green Morocco Plan (GMP). Like many North African countries, Morocco is particularly vulnerable to climate change and its agriculture is expected to result in a major transformation. A three-dimensional impact assessment of the Tadla-Azilal agricultural zone was carried out, covering the biophysical, economic and socio-institutional aspects of the region.

The availability of water is a crucial concern for Morocco in terms of its future agricultural production and economic viability. The biophysical study focused on crop suitability under different climate scenarios, taking into account the local soil types and the demand for water. A hydrological model, especially developed for the Tadla-Azilal zone, examined the demand and supply of water and future crop suitability under changing water supply levels owing, in large part, to climate change. The economic analysis included the two key concerns that are linked to climate change impacts on Morocco's agriculture. These are the (i) impact of climate change on future food supply variability and on food security in light of the investment and value chain priorities of the GMP; and (ii) trade-offs between agricultural intensification under the GMP and water use preservation and sustainability. The economic and biophysical analyses converge on the central issue of optimal use of water, given the changing climate conditions.

The socio-institutional evaluation included diagnostic studies that targeted small-scale farmers to evaluate their degree of participation in nationally supported investment programmes and to assess the scope for integrating climate adaptation into their agricultural systems. A socio-institutional analysis was made to examine the nature of governance, linking the government officials who manage the GPM to the smallholder farmers targeted by the investment programmes. This was done in an effort to develop the diagnostic tools to improve vertical (between government and small-scale farmers) and horizontal (greater coordination between agencies) governance to improve the enabling environment for the adoption of climate-adaption techniques and ensure more resilient institutional arrangements.

7.3 Ecuador's banana sector: improving climate resiliency and sustainability

In the case of Ecuador's banana sector, biophysical and economic studies were performed simultaneously to evaluate the scope for transitioning the sector into a higher productivity level and a more sustainable banana system. This took into account the likely impacts of climate change on future production yields.

A key concern in terms of banana production is the high use of pesticides to maximize yield. The economic analysis focused on cost (driven by labour and pesticide inputs) and market structures, as well as the uneven distribution along the value chain, which is creating significant social inequality. The biophysical analysis (i) emphasized the climate change impact on banana suitability in Ecuador; (ii) the implications of the changing climate parameters on the dynamics of pests and disease; and (iii) the likely changes that will need attention immediately and in the future to ensure the continued economic viability of a system that is vital to Ecuador's agricultural economy.

This biophysical analysis also examined the carbon footprint and GHG emissions associated with banana production, including the stages from transportation through to consumption. From a socio-institutional perspective, a study was made of the national social policies to ensure a fairer distribution of returns to stakeholders across the banana value chain, especially with regard to smallholder farmers and banana plantation workers, who play an important role as constituents within Ecuador's main agricultural industry. The socio-institutional analysis included the issue of governance relating to the banana value chain, not only within Ecuador (labourers, producers, exporters), but also beyond its borders (consumers).

The studies have improved the articulation of Ecuador's existing banana policy with respect to the responsible environmental management of pesticides and Ecuador's social responsibility towards its workers, including fair wage distribution. The impact of climate change on Ecuador's future banana production has been found to be insignificant, unlike in other key banana-producing countries. The results of climate change impact on the dynamics of pests and disease in Ecuador, however, will require further research, since the results, thus far, are not conclusive in terms of the future behaviour of pests and disease on the banana industry.

This report focuses on the Ecuador case. It describes the different studies undertaken in relation to the impacts of climate change on Ecuador's banana industry.

©FAO/Aziz Elbehri

CHAPTER 2:

ECONOMIC AND POLICY ANALYSIS OF THE BANANA SECTOR IN ECUADOR AND IMPLICATIONS FOR SOCIAL AND ENVIRONMENTAL SUSTAINABILITY

Aziz Elbehri *

---

* Trade and Markets Division, Department of Economic and Social Development, Food and Agriculture Organization of the United Nations (FAO), Rome

1. Introduction

Bananas are among the world's leading four crops including wheat, rice and maize. They are usually grown in developing countries within humid tropical zones and are exported to industrial markets, as well as to emerging economies for the rising middle class. As a highly traded commodity, the banana is an integral part of the global value chain. The modern banana production systems used in most countries with tropical climates, however, have resulted in a significant cost not only to the environment due to the prolonged use of pesticides, but also to social inequality that is linked to labour practices and to the disparate distribution of the value added. Today's banana value chain has been characterized as an environmental and social drawback, despite its economic efficiency.

The environmental and social issue, however, is not new. The debate on the negative externalities of bananas has been ongoing since the 1990s, when retailers took over the multinational companies to become the market leaders. Retailers, close to the sensitivities and the demands of the consumer, responded to the heated complaints by environmental groups and nongovernmental organizations (NGO) relating to the negative environmental and social impacts of banana production systems. They devised voluntary standards, norms, protocols and certification schemes as a means for self-regulation in order to allay consumer concerns. These schemes, however, have been limited in their transitional efforts to curb the impacts and create a more sustainable and equitable system. Moreover, the issue of sustainability has become a more pressing concern due to the rising challenge of climate change and the urgency to address its already manifest effects.

An integrated approach to address the complex issues of climate change in this context is required - one that can coherently integrate the economic, environmental and social dimensions. To begin, an in-depth economic analysis of the banana value chain is required to establish the principal implications to environmental and social sustainability. The economic analysis should include market, institutional and policy characteristics. In order to provide more concrete recommendations, an analysis of governance structures along the value chain should also be undertaken.

This review examines the economics of banana value chains and the implications of sustainability in the case of Ecuador. It is a part of a larger study relating to the sustainability of Ecuador's banana production in terms of climate change. The larger project, undertaken by FAO on behalf of the Government of Ecuador, was initiated to support the capacity of the Government of Ecuador to mainstream climate adaptation within its agricultural policies and strategies.

Ecuador is one of the leading banana producing and exporting countries. The banana is significantly important to Ecuador's economy, and represents 22 percent of total world exports, 27 percent of total agricultural exports and 8 percent of the value of all exports (including oil). The banana sector employs a large proportion of Ecuador's workforce and over a tenth of its population is economically tied to the production of bananas and its affiliated businesses (PRO ECUADOR, 2013).

The structure of this review includes three sections. Section 1 provides a general introduction of the banana industry in Ecuador and includes the ecology, evolution of the industry, and geography of banana production. Section 2 includes an in-depth economic analysis of the banana value chain, covering the key stages and players within the value chain up to the consumer. Section 3 reviews the Ecuador's current banana policies, its key objectives and the challenges relating to policy implementation. Section 4 includes a general discussion that will identify the key salient economic, environmental, social and governance aspects of sustainability.

2. The banana sector in Ecuador

2.1 Banana ecology and disease

Banana plants derive from the *Musa* genus (i.e. *Musa acuminate*, the A genome) and *Musa balbisiana* (the B genome) and have evolved through a large number of landraces and cultivars.[1] Bananas are grown in humid tropical regions and require relatively high temperatures, ranging from 18-30°C, and an ample supply of water throughout the year - between 100 mm and 180 mm a month. Bananas also require deep soil with good drainage. They remove large amounts of soil nutrients with the harvest of the fruit.

Bananas are permanent crops and can be cultivated up to 30 years continuously. As a result, soil fertility declines rapidly after the plant's first 3-5 years, causing a reduction in the yield of bananas, with soil degradation occurring further after 10-15 years (Chambron, 2000). The depletion of nutrient soil on banana plantations, therefore, significantly hinders sustainability. The land that is abandoned after continuous banana production often is left with severe soil degradation and, thus, cannot be alternatively used. This creates serious income loss and unemployment in neighbouring communities, an example of which has been Costa Rica, where banana companies have abandoned their plantations in the Caribbean coast of the country due to unsuitable soil, shifting production to its Pacific coast (Chambron, 2000). In Ecuador, where the majority of banana plantations have been in operation for over 20 years, many of the plantations are reportedly abandoned and have become incubators for diseases that are spreading to neighbouring plantations.

The vast majority of exported bananas are of the Cavendish variety. These are produced on monocrop plantations with close spacing and plant density, making it highly susceptible to pest and disease outbreaks. The disease vulnerability also arises from the fact that commercially produced bananas are derived from a limited number of landraces that reproduce asexually, resulting in a narrow genetic pool and making bananas vulnerable to pests and disease (FAO, 2003).

---

[1] Most edible bananas are derived from two wild species in the genus Musa (i.e. *Musa acuminate*, the A genome and *Musa balbisiana* (the B genome) (Simmonds and Shepherd, 1955). There are over 500 cultivars of bananas (Stover and Simmonds, 1987; Perrier and Tezenas du Montcel, 1990) that are being grown for many different purposes: for the desert, cooking or cultivars for dual use. This report focuses only on the desert types, in particular the Cavendish variety.

Consequently, pest control with agrochemicals has become the cornerstone of modern commercial banana production, creating critically adverse environmental effects.

Among the key diseases that currently inflict the banana are Black Sigatoka (BS), Fusarium wilt and parasitic nematode infestations. The most severe of these is BS (*Mycosphaerella fijiensis* Morelet), a fungal disorder that decreases photosynthesis, reduces the size of the fruit and induces a premature maturation, thus lowering yields and resulting in the rejection of fruit to be exported (FAO, 2003). In Ecuador, banana plantations have been affected by BS since the late 1980s. In 2012, the outbreak was particularly severe, made worse by the heavy rains of April and May and the presence of many abandoned plantations in Los Rios and Guayas. Over 70 000 hectares (ha) were affected by the outbreak (LACENA) in economic terms.

2.2 Evolution of the banana industry in Ecuador

The banana industry prospered in Ecuador after World War II and replaced the cocoa industry after its demise in the 1920s.[2] In 1948, President Galo Plaza initiated a development programme to foster banana growing, which included government agricultural credits; the construction of ports and a coastal highway; price regulation; and assistance for the control of banana disease. Aided by an ideal climate for banana crops, Ecuador rapidly caught up with the rest of Central America, the dominant banana producing region during prewar years. In addition to government support and significantly lower labour wages, the positive environmental factors – such as the absence of hurricanes, cyclones, and disease, common in Central America – worked in Ecuador's favour. By 1952, Ecuador had become the world's largest exporter of bananas and by 1964, the country had reached 25 percent of global banana exports, more than all Central American banana-producing countries combined (Maldonado, 1987).

Until the 1960s, the principal type of banana produced for export was the Gros Michel. This variety was grown under intensive but shifting cultivation with very low productivity (approximately 20 tonnes per ha), a high level of deforestation and low use of agrochemicals. The Gros Michel variety was almost entirely destroyed in the late 1960s by an outbreak of Fusarium wilt, known as the Panama disease, and was replaced by the Cavendish variety. The latter was more resistant to the Panama disease and to hurricanes, although more susceptible to damage when handling (FAO, 2003). The introduction of the Cavendish type required that the bananas be packed in boxes (as opposed to stem-hung below deck). While the adoption of this variety was rapid in Central America, it soon became the dominant type of banana worldwide. In any event, after only ten years, the Cavendish banana fell prey to a new disease – BS, which has become more aggressive and has caused substantial damage over the years.

The bananas that are produced in developing countries with a tropical climate are mainly exported to and consumed in the high-income countries of the Northern Hemisphere. This makes commercial export an integral part of the

---

[2] Banco Central del Ecuador (1992).

global value chain from inception. In addition, the high perishability of the fruit requires close coordination from the plantation to the consumer, thus significantly favouring a vertically integrated supply chain that is dominated by multinational corporations (MNC). Until the 1990s, MNCs controlled all key stages of the supply chain - from production and transport to the sale to retailers. In addition, they adopted clear supply strategies that were based on minimizing risk, diversifying the supply base and keeping production costs to a minimum, particularly by maintaining low wages. The dynamics of economics, political stability and disease were key factors in the selection by MNCs of which country to invest in and from which to withdraw. In Ecuador, the agrarian reforms of the 1960s - which limited direct land ownership by MNCs - encouraged the MNCs to leave the country. The exception to this was Dole Food Company, which has maintained its production and supply of banana (Human Rights Watch, 2002) in Ecuador. During the 1970s, nevertheless, MNCs returned to Ecuador (i) in response to the outbreak of BS in Central America and Colombia; (ii) in reaction to the imposition by these countries of export taxes on bananas and (iii) in reaction to the increased organization of unions, resulting in higher workers' wages (Human Rights Watch, 2002).

2.3 Geography and the farm structure with regard to the banana industry

2.3.1 Geographic locations

Ecuador has nearly 12 million ha of land under agriculture, of which over 11 percent is occupied by permanent crops, notably bananas, sugar cane and oil palm. According to the Ministry of Agriculture and Livestock (MAGAP), banana cultivation accounts for 10 percent of the total agricultural area in the country and occupies over 165 000 ha (MAGAP, 2013).

Nearly all the bananas produced in Ecuador are located in three provinces in the lowlands of the Pacific coast – El Oro, Guayas, and Los Ríos. These are characterized by a humid, tropical climate and rich soils - ideal conditions for banana growing (Human Rights Watch, 2002). The province leading banana production is El Oro, located along the southwestern coast. The area is mainly flat, with a few low mountains, and is dry. Average temperature is 23°C and the rainfall range is from 200-1 500 mm annually. Guayas is the second largest province in agricultural land area (810 000 ha) and is dominated by two permanent crops: bananas and sugar cane. Bananas are planted on 41 700 ha, with an annual average production of approximately 1.6 million metric tonnes for the 2009-2012 period (MAGAP). The banana production by province in recent years is shown in Table 1.

2.3.2 Farm size

The Ecuadorian banana industry is highly diverse in terms of farm size, multiplicity of exporting firms, and supporting industry. The banana plantation structure in Ecuador is characterized by a large number of small and medium-size producers (Table 2). Approximately 79 percent of all producers nationwide have farms that do not exceed 30 ha; however, they only own 25 percent of the total area planted

Table 1 Production of bananas in Ecuador by province, 2012 (metric tonnes)

	Los Rios	El oro	Guayas	National
2009	3 744.6	1 861.7	1 554.7	7 637.3
2010	3 887.1	1 892.6	1 719.4	7 391.1
2011	3 670.1	2 443.7	1 692.7	7 427.8
2012	2 753.7	2 269.9	1 585.1	7 012.2

Source: INEC; Encuesta de Superficie y Producción Agropecuaria Continua (ESPAC), (2012)

Table 2 Banana farm size distribution and average yields in Ecuador

Plantation size	**Producers (%)**	**Area (%)**	**Yield (mt/year)***
Small (0-30 ha)	79	25	28.9
Medium (30-100 ha)	16	36	38.5
Large (more than 100 ha)	5	38	57.7

Source: MAGAP (2013)
* National Information System (MAGAP)

in bananas. Of these, over 60 percent of banana farms operate plantations of less than 10 ha (the average size is 6.8 ha) and 10 percent of all farms cover less than 2 ha (MAGAP). Approximately 5 percent of all producers own more than 100 ha but control 38 percent of the total area planted. The average size of a banana farm is 23.3 ha.

3. Analysis of the banana value chain: Key stages and principal stakeholders

3.1 Banana production

3.1.1 Field management and packing practices

The banana plant is a perennial crop. In Ecuador, the plant is usually of the Cavendish variety and propagates from the offshoots from a mother plant. The first bananas can be harvested after nine months from planting. The offshoots are cut down to allow for new offshoots to grow from the same plant, which flourishes continuously over many years. Since bananas require a substantial supply of water, supplemental irrigation is sometimes provided, either by pumping the water from nearby rivers or through gravity-fed systems. A good drainage system is also essential so as to evacuate excess water. Fertilization is needed, since bananas demand substantial nitrogen and potassium. This is applied by way of a comprehensive procedure with specific amounts and application cycles. Fertilization can also be applied during irrigation (fertigation) (FAO, 2003).

Pest and disease control is an essential component in the management of banana production. Aerial, as well as terrestrial, applications are commonly used in Ecuador, with large variations in the types and rates of substances applied from plantation to plantation. Typically, the banana fruit itself is covered with plastic to protect the fruit from insects and from the application of insecticides.

Once the fruit is harvested, it is transported to the processing area, either manually or by way of an aerial cableway. Bananas are harvested year round on a weekly basis. The production process begins when a banana plant sprouts from the root, from where its parent plant was cut, and ends approximately one year later when its fruit is harvested and loaded onto a truck (Human Rights Watch, 2002). The main field and packing plant operations are summarized in Table 3.

Table 3 shows the critical importance of labour in the banana production. Even the smallest farm will hire permanent workers (Roquigny *et al*., 2008). According to a MAGAP estimate, the average national number of workers on a banana plantation is 1.1 person per ha for direct labour and 1.5 for direct and indirect

Table 3 Main banana field and packing plant operations

Field operations	Packaging plant operations
• Weeding	• Removing plastic from the harvested banana stalks
• Applying weed and worm killer	• Picking flower remains off the fruit
• Weaving long plastic covers around bananas to prevent them from damaging each other	• Cutting bananas from their stalks
• Covering bananas with insecticide-treated plastic bags	• Making banana clusters
• Tying insecticide-treated plastic strips around plant stalks	• Discarding bananas that do not meet company standards
• Cutting yellow banana leaves	• Washing and weighing the fruit
• Tying plants to each other or propping them up with wooden poles to ensure stability	• Sticking company labels on each banana cluster
• Tying coloured strips around plant stalks to indicate growth phases and monitoring these phases	• Applying post-harvest pesticides
• Harvesting fruit-laden stalks and transporting them to the packing plant*	• Boxing the fruit
• Cutting the remaining stems after harvesting	• Loading the boxes onto a truck
	• Discarding waste from the banana production process

Source: Human Rights Watch (2002)

* Two types of workers are required to harvest bananas: a cutter and a backer. The cutter cuts down the plant with a machete, while the backer waits for the cut stem to settle on a thick cushion on his/her shoulder. The cutter then chops the stem to enable the daughter plant to take over as the main stalk. The backer carries the fruit and attaches it to a nearby overhead cableway where the stem is transported to the packing shed (Vanzetti *et al*., 2005)

labour. Given that the estimated total area under banana cultivation was slightly over 165 000 ha in 2012, the direct and indirect labour force working on banana plantations is approximately 250 000 workers.

There are two types of banana production systems in Ecuador: organic and conventional. Organic farms neither use synthetic chemicals for fertilizers nor pesticides. They use natural plant extracts, manure or other approved products for organic production. Organic farms also apply different fertilizer formulas than do conventional farms. Table 4 shows data relating to the use of fertilizer and pesticides for a sample of organic and conventional farms, which were collected in Ecuador as part of a life-cycle analysis (FAO, 2014).

In general, organic farms use fewer inputs for fertilization and pest control. All fertilizer inputs are from natural sources, including compost, lime, mineral potassium sulphate, poultry manure and phosphate rocks as sources. For pesticides, plant extracts, such as Timorex Gold and other approved products, are used. Average banana yields on organic plantations are lower (33 versus 39.9 metric tonnes (MT)/ha), but not significantly as previously reported in literature.

3.1.2 Cost of production

The cost of banana production per ha varies, depending on the farm size and yield level; the technologies used; and levels of inputs. Table 5 provides a detailed cost of production relating to conventionally grown bananas on small, medium and large farms.

What is significant from these details is the high share of labour in total cost. Labour accounted for 48.5 percent of the total cost of production for small farms, compared to 44.6 percent for medium farms and 40.2 percent for large farms. These high shares demonstrate the labour-intensive nature of banana production and why maintaining lower labour wages has defined much of the tumultuous relationships between MNCs and workers' unions, national governments and NGOs.

The second largest cost category in the production of bananas is agrochemicals. This reflects the close dependence of banana management on large applications of fertilizers and pesticides to shore up soil fertility and fight disease. Pesticide expenditures, alone, range from15 to 20 percent of total cost and are higher for small-scale producers who cannot use aerial spraying and need to rely on more costly manual applications.[3] Fertilizer expenditures increase with farm size, from 4.9 percent for small farms to 9.5 percent for large plantations, reflecting a higher nutrient replacement given the higher average fruit harvest per ha.

---

[3] The number of chemical sprayings is linked to the length of the rainy season. Ecuador has four months of rain per annum compared to ten months in Costa Rica. Consequently, the number of sprayings against BS in Ecuador is less (averaging 20 chemical sprayings per annum) than in Costa Rica (averaging between 50 and 70 chemical sprayings per annum) (Chambron, 2000).

Table 4 Input use by organic and conventional banana plantations in Ecuador

Inputs category	Item	Input applications	
		Organic (/ha)	Traditional (/ha)
Farms surveyed		9	8
Average size		34.4	83.7
Average yield		33.0	39.9
Pesticides*	Fungicide (l)	15.9	7.1
	Herbicide (l)		2.9
	Growth regulator (l)	4.7	0.6
	Insecticide (l)	3.6	1.5
	Unspecified pesticide (l)	6.7	
	Pesticide cyclic-N compounds (kg)		11.5
	Pesticide acetamide-anillide-compounds (kg)		0.4
	Pesticide benzimidazole compounds (kg)		1.9
	Pesticide dithiocarbamate compounds (kg)		11.1
Fertilizers	Average fertilizer from algae (kg)	3.9	4.0
	Lime from carbonation (kg)	445.6	83.7
	Potassium chloride (kg)		522.8
	Compost (kg)	988.7	
	Ammonium nitrate (kg)		376.0
	Monoammonium phosphate (kg)		50.0
	Diammonium phosphate (kg)		305.9
	Ammonium sulphate (kg)		236.5
	Calcium sulphate (kg)	224.2	193.5
	Potassium sulphate (mineral) (kg)	1049.7	130.7
	Zeolite (kg)	140.0	
	Poultry manure (kg)	945.1	
	Potassium nitrate (kg)		900.0
	Phosphate rock (kg)	179.3	
	Potassium silicate (kg)		475.0
	Magnesium sulphate (kg)	40.6	13.3
	Zinc sulphate (kg)	91.7	200.0
	Calcium nitrate (kg)		100.0
	Triple superphosphate (kg)		150.0
	Boric acid (kg)	87.0	
	Bórax (kg)	19.0	
	Molasses (kg)	5.2	
	Castor-oil plant flour (kg)	365.1	
	Urea (kg)		393.6
	Ureate (ammonium nitrate) (kg)		225.0

Source: Author's calculations, based on data from FAO. (2014)

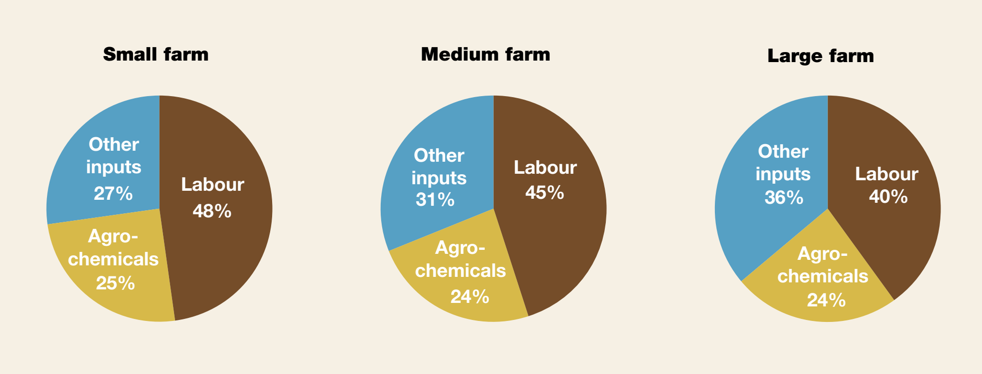
* Organic plantations do not use synthetic chemicals to fight pesticides; they use plant extracts approved for organic plantations (such as Timorex Gold

Table 5 Cost of production for three conventional banana farm sizes in Ecuador

Cost item	**Small farm**		**Medium farm**		**Large farm**	
	Cost/ha	**% total**	**Cost/ha**	**% total**	**Cost/ha**	**% total**
Average number of boxes/ ha/year (Box = 18.5kg)	1 148.5		1 584.6		2 136.6	
Direct labour (/ha)	922.1	13.5	922.1	11.9	922.1	10.3
Indirect labour (/ha)	2 395.7	35.0	2 534.9	32.7	2 681.2	29.9
Harvest and packaging (/ha)	1 070.7	15.6	1 329.3	17.2	1 804.4	20.1
Inputs (/ha)	1 928.3	28.1	2 419.4	31.3	3 037.2	33.8
of which: Fertilizers	*336.0*	*4.9*	*588.0*	*7.6*	*857.2*	*9.5*
Agro chemicals	*1302.7*	*19.0*	*1281.6*	*16.6*	*1294.5*	*14.4*
Other inputs	*289.6*	*4.2*	*549.8*	*7.1*	*885.5*	*9.9*
Equipment and building depreciation (/ha)	338	4.9	338	4.4	338	3.8
Various materials (/ha)	70.9	1.0	70.9	0.9	70.9	0.8
Taxes and miscellaneous services (/ha)	127.9	1.9	127.9	1.7	127.9	1.4
Total cost of production (/ha)	**6 853.7**	**100**	**7 742.6**	**100**	**8 981.7**	**100**
Total cost of production per box (18.5 kg)	5.97		4.89		4.2	
Producer profit (23%)	1.37		1.12		0.97	
Selling price	7.34		6.01		5.17	

Source: MAGAP (unpublished data, communicated to author; January 2014)

Figure 6 Share of labour and agrochemicals in total cost of production for small, medium and large conventional banana farms



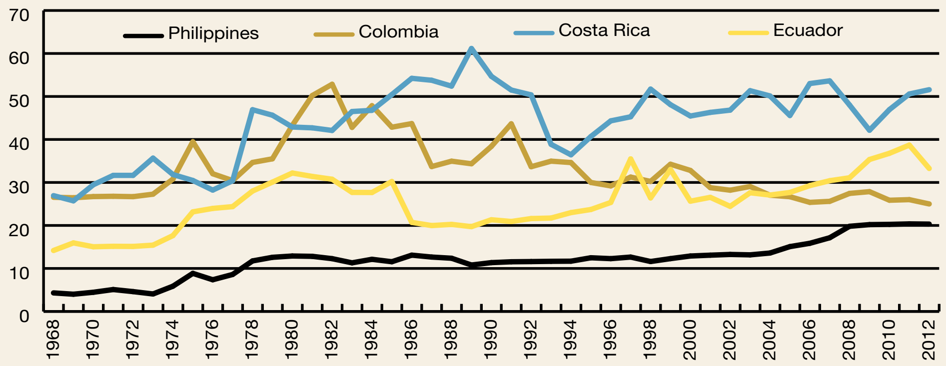
Source: MAGAP

3.1.3 Banana yields

Table 2 shows Ecuador's average banana yields for 2012 by farm size. Small farms (less than 30 ha) average 28.9 MT/ha and rise to 38.5 MT/ha for medium farms (from 30-100 ha) and 57.7 MT/ha for larger plantations (over 100 ha). The national yield average for Ecuador in 2012 was 31.7 MT/ha. This average is much lower compared to Costa Rica, which averaged 46.9 MT/ha in 2012 (according to Corporación Bananera Nacional of Costa Rica). In Ecuador, the lower national average reflects the prominence of small-scale farmers, while in Costa Rica it is a reflection of the dominance of large-scale plantations. The low average yields of small-scale plantations in Ecuador are a result of a lack of investment in improved technologies, as well as a consequence of their insecure and variable income due to often selling products on the spot market and being subject to market price variability. This is due, in part, to the weak position of small-scale plantations in terms of price bargaining, with the much stronger exporters better able to offer lower prices. Lower and variable income, in turn, reduces the incentives for re-investment in productivity-enhancing technologies.

Banana yield trends over the years demonstrate a steady increase, except in 2012 when the yield dropped because of a heavy infestation of BS (Figure 7). When comparing Ecuador to its competitors, it is clear that Costa Rica has witnessed a dramatic improvement in yields over time, reaching a peak in 1990, followed by a drop during the 1990s and a recovery since 2000, fluctuating at approximately an average of 50 MT/ha. The Philippines, another major banana exporter in Asia, has also experienced a steady yield increase - although from a lower starting point - reaching 20 MT/ha in 2012. By contrast, Colombia's banana yields have been steadily eroding ever since their peak in the early 1980s (approximately 50 MT/ha) and dropping to 25 MT/ha by 2012.

Figure 7 Banana yield trends in Ecuador and other major exporters, 1961-2012



Source: FAOSTAT

3.2 Banana exports

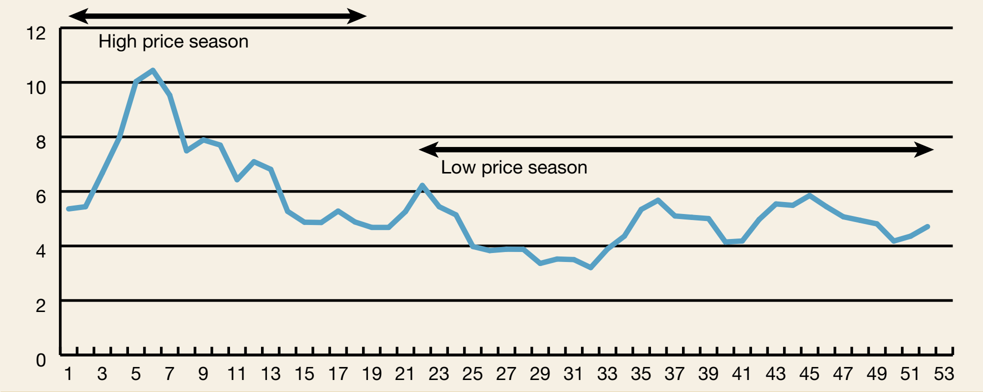
The Cavendish banana is produced mostly for export, with the exception of India and China, where the population is significant and bananas are mostly sold to large domestic markets. Demand by member countries of the Organisation for Economic Co-operation and Development influences the price of banana and, hence, the supply. High-income markets broadly correspond to two seasons that represent a high demand and a low demand. These, in turn, reflect higher and lower prices, respectively.

Figure 8 shows the weekly free-on-board (FOB) prices for Ecuador's exports throughout the year (averaged over five years) and separates the high-demand/high-price season (first 22 weeks of the year) and the low-demand/low-price season (rest of the year). One of Ecuador's key sources of comparative advantage is its ability to produce most fruit during the high-demand season (winter) in contrast to Central American counties that produce more fruit during the low-demand/low-price season.

Since the 1960s, Ecuador has become the largest banana exporter in the world. Among its many sources of competitive advantage are a favourable climate year round on its coastal areas, allowing for an uninterrupted supply of bananas, adequate packaging capacities and shipping systems, and relatively low labour costs. Two of Ecuador's competitors, Colombia and Costa Rica, have recently signed a trade agreement with the European Union (EU) for slightly improved access to EU markets as a result of lower tariffs (€124 per tonne to Europe compared to €132 paid by Ecuador). These countries also now benefit from shorter transit routes compared to Ecuador, which requires four extra days through the Panama Canal (LACENA).

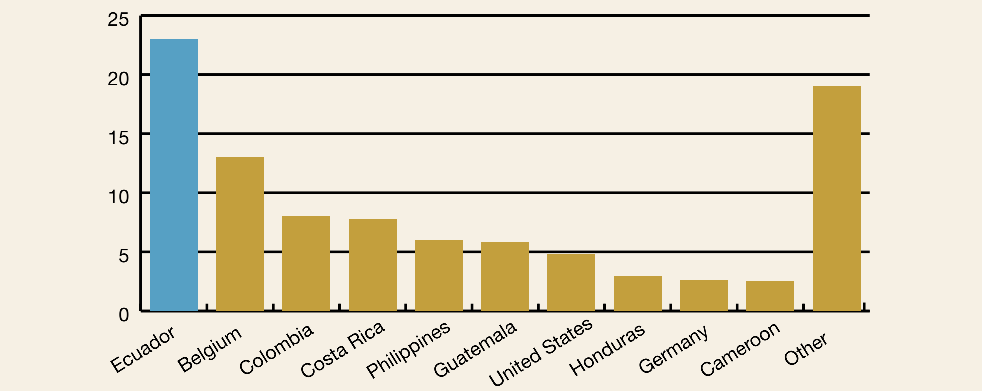
Ecuador exports nearly 95 percent of its banana production, and its share of world banana trade amounted to 22 percent in 2012 (Figure 9). It exports as much as the combined volume of the next three leading Latin American countries:

Figure 8 Weekly spot market price for banana, 2006-2013 (average)



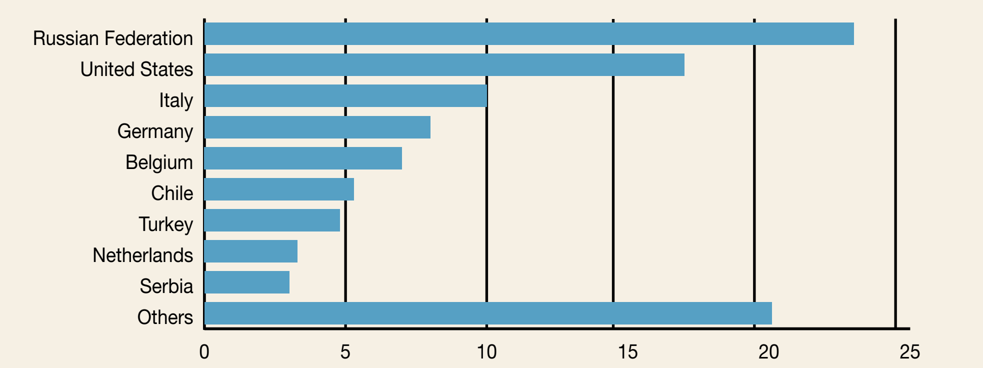
Source: Author. Calculations based on data from MAGAP

Figure 9 Major banana exporters, 2012 (% of total)



Source: PRO ECUADOR (2013)

Figure 10 Ecuador main banana export destinations, 2012



Source: Central Bank of Ecuador, extracted from PRO ECUADOR (2013)

Colombia, Costa Rica and Guatemala. European countries, such as Belgium and Germany, re-export the bananas elsewhere in Europe and are included in FAO statistics as major banana exporters.

Figure 10 shows the major export destinations of Ecuadorian bananas. In 2012, Ecuador exported bananas to 43 countries. In 2012, Russia was the main destination with 22 percent of total exports, followed by the United States and the traditional European markets, including Belgium, Germany, Italy and the Netherlands (MAGAP).

In recent years, Ecuador has expanded its exports into relatively new markets, such as Chile and Turkey, as well as other smaller markets in Eastern Europe and the Middle East. Diversification of exports is a key concern for Ecuador.

Organic banana producers receive higher prices than conventional banana producers, despite the fact that they sell to the same exporters who handle conventional bananas and they face the same price bargaining mechanism. Unlike bananas that are certified under the Fairtrade label, there are no fixed prices for organic bananas, which are subject to buyer-seller negotiations and, hence, the risk of the commoditization of organic bananas. This creates uncertainty in the organic market and a source of significant variation in the conditions of supply and demand. This explains, in part, why Ecuador's organic exports have sharply declined over the last five years, dropping from 25 000 boxes exported per week five years ago to only 13 000 boxes per week in 2012 (LACENA).

3.2.1 Exporters

The number of registered export companies in Ecuador in 2012 was 224, including companies that only export during the high-price season. In 2013, there were 172 active exporters, with the topmost 20 exporters accounting for 62 percent of total banana exports. Table 6 summarizes the export shares of the leading ten banana exporters for 2013. Among these, MNCs are represented through local subsidiaries. Dole Food Company, along with its subsidiary, Union de Bananeros Ecuatorianos S.A., secured the highest export share at 10.5 percent of total. Chiquita is represented by Brundicorpi S.A. (3.5 percent total share) in Ecuador, while Del Monte Foods Inc. is represented by Bandecua S.A. Ecuador's own company is Noboa – one of the leading five banana companies worldwide and which is also among the topmost exporters of bananas in Ecuador.[4] Among the international companies, only Dole Food Company has maintained direct production, owning 900 hectares in the country.

Table 6 Export shares of the leading ten banana exporters in Ecuador

Exporter	**Export market share (of total Ecuador exports)**
Union de Bananeros Ecuatorianos S.A. (Dole subsidiary)	10.5
Trusfruit S.A.	7.3
Reybanano del Pacific C.A.	5.2
Obsa Oro Banana S.A.	4.2
Comesur S.A.	4.1
Brundicorpi S.A. (Chiquita subsidiary)	3.5
Asociación de Agricultores Bananeros del Litoral	3.4
Ecuagreenprodex S.A.	2.7
Baguilasa S.A.	2.2
Caragrofrut S.A.	2.1

Source: Unibanano (unpublished; communicated to author; January 2014)

---

[4] Dole Food Company (United States), Chiquita (USA), Del Monte Foods Inc. (based in the United States), Fyffes (Ireland), Noboa (Ecuador).

Multinational corporations tend to use Ecuador as a buffer, sourcing bananas from Ecuador when there is a shortage from other sources (Human Rights Watch, 2002).

It is usual for export companies (local or MNCs) to obtain bananas through a variety of contract arrangements with third-party producers, ranging from exclusive associate producer relationships to periodic contracts or purchases through the open spot market. Although banana exporters partly control production through contracts with suppliers or through direct ownership of banana plantations, their interventions stop at the border (Roquigny *et al*., 2008).

Prices paid to producers were determined by the exporters, who had tight control over farm management (e.g. input use, disease control), until Ecuador reformed its Banana Law in 2011 (see Section 4). Export companies also provide the suppliers with banana boxes, labels and palettization equipment, among others. Equipment costs are then deducted from the price of the boxes paid to the suppliers (Roquigny *et al*., 2008).

3.2.2 Other suppliers to the banana industry

In addition to producers and exporters, the banana supply chain is supported within Ecuador by stakeholders within the services sector, including those relating to cardboard manufacturing, ground transportation, plastic supplies, agricultural inputs and ocean shipping inspection, testing and certification, aerial fumigation, plant breeding and banking and insurance. Table 7 lists the value of gross sales by service providers for 2012.

3.3 Ocean shipping

Three significant innovations have made it possible to transport bananas over long distances: refrigeration, the containerization of shipments and the use of pallets. Refrigeration during transport was developed during the late 1960s

Table 7 Key supporting industries for banana and their market shares

Service industry	**Annual sales (million USD)**
Cardboard box manufacturers (the banana sector absorbs 90 percent of the products)	260
Ground transportation (approximately 275 000 trips per year)	70
Ocean shipping	1.500
Plastics	130
Agricultural inputs (the banana sector's share represents 60 percent)	600
Inspection, testing, certification and verification services	
Aerial fumigation service providers	40
Plant breeders	
Banks and financial companies, insurance	

Source: Venzetti *et al* (2005)

(FAO, 2003). Controlled atmosphere in ships (reefer boats) began in the early 1990s, and computerized systems for monitoring atmospheric conditions were introduced in the late 1990s. These developments, plus the introduction of a ripening process with ethylene, made it possible to transport green (latent) bananas and allow for the delivery of a fully ripe fruit at the point of sale (FAO, 2003).

A further technological innovation was the introduction of refrigerated containers, which allow farmers to harvest on a continuous basis - as opposed to ship's days - and reduce handling costs at port. Pallets are increasingly being used in container shipping, as these can accelerate downloading and save on distribution costs by allowing loads to be divided into smaller units (FAO, 2003). In Ecuador, the use of containers has increased from 20 percent in 2007 to 80 percent in 2012 (LACENA).

3.4 Retailers

The increasing use of multimedia and the Internet has had a transformative effect on the food system, in general, vastly improving supply chain logistics, including facilitating the drawing up of contracts and speeding up access to market information. These innovations have contributed to lower communication and transaction costs. They have also facilitated the arbitrage of prices and loosened the vertical integration of MNCs, prompting a market power shift towards the retail sector, which has gained in concentration through the rise of the supermarket. Supermarkets have taken on a more dominant role in leading global food value chains, including that of the banana.

The shift in market power from MNCs to the retail food sector during the 1990s has transformed global bananas into "buyer driven chains". These new market leaders (supermarkets) began to set the rules, based on a horizontally coordinated market structure which is regulated by standards and norms. Contractual arrangements with suppliers define the conditions for production and distribution of bananas without direct ownership (Roquigny *et al*., 2008). Under this new market structure, supermarkets now impose specific product requirements (origin, class, size and packaging) that suppliers must adhere to and bear the full cost for. MNCs also have changed their banana supply strategies by initiating long-term supply contracts with independent medium- and large-scale producers. This has significantly undercut the role of MNCs, which have had to adjust accordingly by moving away from direct production control and by developing new strategies to reduce their risk exposure (e.g. weather conditions, political activism) and, at the same time, reduce their social obligations to plantation workers. By resorting to third-party suppliers through contracts, MNCs now manage to maintain a firm grip on production by setting the terms and conditions in their contracts with plantation owners and suppliers.[5]

---

[5] The direct involvement of MNCs in the production process through company-owned plantations varies by country. They are still strongly present in Costa Rica, Honduras and Panama, but not in Ecuador or Nicaragua, except for Dole Food Company, which maintains some production in Ecuador. MNCs have also diversified in other regions, notably in Africa and Asia, where they are present through joint

The retail end of the supply chain mounted its market dominance through the help of third-party certification bodies, selected by the retailers, to enforce standards and norms. In the 1990s, third-party certification schemes quickly became the choice mechanism to enforce private standards and norms. These standards go beyond the issues of safety and quality and include product attributes and benchmarks that are meant to enforce compliance by downstream operators and extract rents by the retailers and third-party certification providers. The perishability of the banana and the high degree of concentration at the retail sector level provide the latter with a powerful lever to enforce compliance with voluntary standards by downstream operators (Robinson, 2010).

Under this system of quality control and traceability, all risk is borne by the exporters and producers. In the case of rejected bananas, the exporters and producers are contractually liable for paying the damages at the Cost-Insurance-Freight price. As the exporters run the risk of ruining their reputation and losing their customers they, in turn, establish strict quality management and control systems in the banana chain with the producers. Farmers, in turn, are compelled to comply or run the risk of being excluded from the export market. Producers and producer groups or associations sequentially invest in internal quality management control. A banana producer organization would usually hire a technician for 30 members; the technician then visits the farmers regularly, assists them with production and packaging, and provides advice on quality and standards-related issues. Quality control is also carried out at the packaging station by the exporter's staff (Roquigny *et al*., 2008).

The accredited certification bodies are located outside the producing country and are closely associated with retailers - their key customers. Producing countries, such as Ecuador, are struggling to localize this critical service provision domestically and internalize the revenues. While Ecuadorian and other Latin American producers are keen to encourage home-grown certification entities that meet international norms, they have yet to gain acceptance from the retail industry, which prefers to select certification providers close to the consumer market.

To be organic or Fairtrade-certified, producers must be inspected at least once a year by the certifier and certification is done at the farm level.[6] The certification body transfers much of the cost of compliance to the grower. This means that

---

ventures. Del Monte is present in Cameroon and Dole Food Company in Cameroon and Côte d'Ivoire. Chiquita, Dole Food Company and Del Monte Foods Inc. have agreements or joint ventures with banana producers in the Philippines (Rabobank, 2001).

[6] Fairtrade label certification is carried out under the auspices of the Bonn-based organization, Fairtrade International (FLO, 2009), which includes provisions allowing freedom of association by workers, such as freedom to participate in farmer associations and cooperatives and engage in discussions on wages and accommodation, occupational health and safety, prevention of child or forced labour. The Fairtrade label also includes some environmental criteria for bananas, such as the use of buffer zones and a ban on herbicides. Standards also stipulate minimum prices, set by Fairtrade International, plus the Fairtrade premium, and traders pay farmers in advance up to 60 percent of the value of the merchandise (FAO, 2003).

producers must step up to an internal regulatory system as a prerequisite to qualify for organic certification as a producer group. Only a percentage of certified producers (10-20 percent) are inspected. This form of quality control is very similar to the ones applied by exporters for conventional bananas. Moreover, producer organizations cannot select their certification agency; this is usually imposed on the exporter (buyer) of the organic banana. As a consequence, it is not unusual for producers and their organizations to be regulated by several certifiers if they supply different buyers, thus adding to producer costs (Roquigny *et al*., 2008).

Despite the Fairtrade certification and the premium price for fair trade and organic bananas, the retail sector approaches alternative banana value chain (fair trade or organic) with the same strategies and requirements as they do in relation to the conventional banana value chain. The retail chains decide the type, shape and quantity of conventional, organic and fair trade bananas they wish to sell. Although organic and Fairtrade certifications may encourage the establishment of long-term contracts and relationships between importers and producers, importers usually adopt the same strategies and apply the price criterion as much as they do on the conventional banana value chain (Roquigny *et al*., 2008).

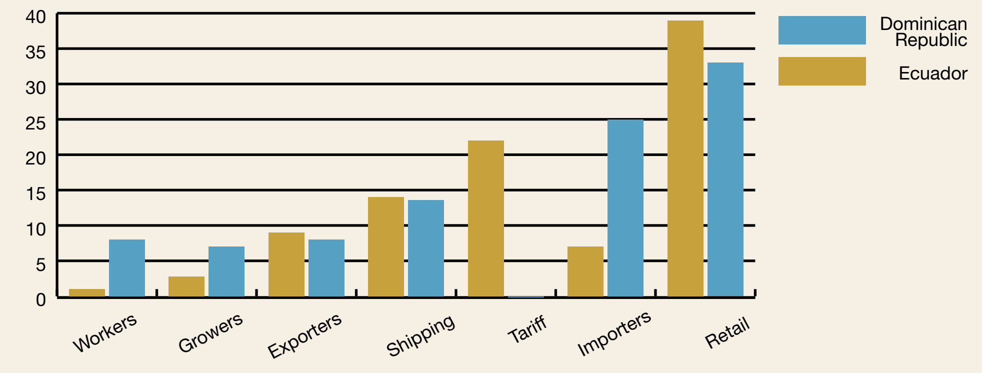
3.5 The impact of market power on the banana value chain

Given the market dominance of the global banana chain by the retail sector and the ability of the retail sector to establish the rules for the supply chain, it is not surprising that the value distribution becomes distorted and slants towards the retail end of the chain. Furthermore, since bananas are not transformed after harvest, it is easy to analyse the value distribution unencumbered by processing considerations and value addition. This uneven value distribution between the key chain players has been consistently demonstrated in various analyses and market surveys.

Chambron (2000) reported the return value along the banana value chain for conventional bananas in the Dominican Republic and Ecuador, showing that workers receive only 1-3 percent of final value in medium- to large-scale plantations (Figure 11) while producers receive 7-10 percent. On the other hand, the retail/supermarket chains capture the largest share of total value - between 34 and 40 percent - while the rest is split between exporters, shippers and importers which, together, capture from one third to two fifths of the total value that is generated. Under this distribution, the share of the final banana price that is captured within the producing country varies from 12 percent (Ecuador) to 25 percent (Dominican Republic). The larger share relating to the Dominican Republic reflects the absence of large MNCs and the limited role of vertical integration (Vorley, 2003).

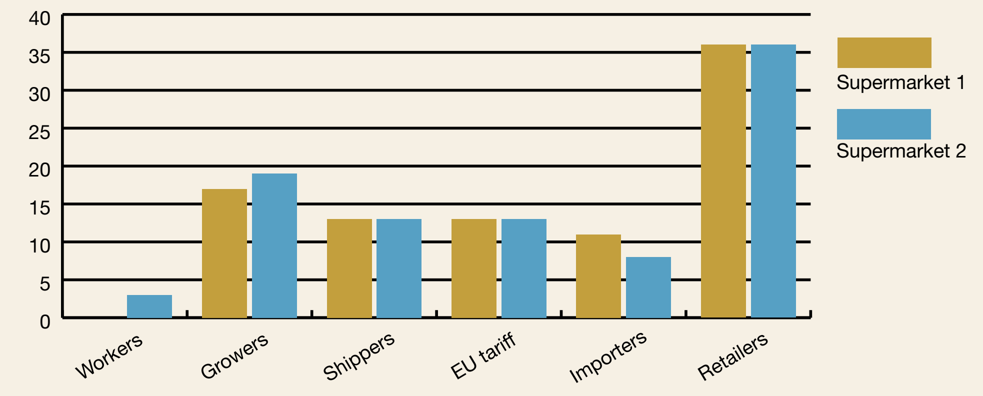
This uneven distribution of banana value shares is fairly consistent across many studies. Roquigny *et al*. (2008) report that less than one fourth of the final banana price has remained in the Dominican Republic, with farmers receiving approximately 13 percent of the final retail value, while exporters and shippers secured 5 percent and 9 percent, respectively. A 2006 study on conventional bananas in Costa Rica, sold in the United Kingdom (Figure 12), shows the same

Figure 11 Share of value capture along the banana value chain



Source: Chambron (2000)

Figure 12 Value distribution for banana in two supermarkets in the United Kingdom, 2006



Source: Banana link

distribution of margins along the value chain. From €22.4 paid by the consumer for a large box of bananas, the retailer secures 38 percent of the share, while the rest is split between importers/ripeners (9.5 percent), EU tariffs (14.5 percent), shippers (14.5 percent), plantation owners and exporters (20.5 percent) and plantation workers (3 percent). The same survey of a second supermarket showed that the retailer captures 38 percent of the consumer price; importers/ripeners, 12 percent; EU tariffs, 14.5 percent; shippers, 14.5 percent; plantation owners and exporters, 18.5 percent; and plantation workers, 2.5 percent (Banana Link).

This irregular and fairly consistent distribution of banana value share also exists in relation to organic or Fairtrade Certification bananas, despite the higher retail prices that these bananas fetch. In 2006, a survey from the Dominican Republic showed that the retail price of Fairtrade Certification bananas was 12 percent higher than that for conventional bananas. Looking only at the portion of the chain within the producing country (FOB prices), alternative banana chains (organic or fair trade) generate slightly higher values that are secured by exporters and lower shares that are secured by importers, but the value share seized by the retailer does not significantly change for these niche markets compared to that relating to conventional bananas (Roquigny *et al*., 2008).

A 2007 study on value distribution for the Fairtrade Certification and organic banana chain in the Dominican Republic shows more or less the same results (Roquigny *et al*. 2008). This is due to the fact that these alternative banana chains involve the same stakeholders and use the same logistics and commercial relations as their conventional counterparts. Thus, alternative banana chains are not fundamentally different from the conventional chains. Only through more direct relations between producers and consumers can there be a significant shift in the relative value capture towards producers and workers than is currently the case.

4. Analysis of Ecuador's banana policy

Since the election of the new government in 2008, Ecuador has placed high priority on the Constitution's Article 344, which states that "the State shall promote equitable access to factors of production, to prevent the concentration or hoarding of factors or production resources, promote redistribution and delete privileges or inequalities in their access. It must also encourage and assist the development and diffusion of knowledge and technologies aimed at the production processes."[7]

The banana industry, which involves close to 10 percent of the total population, is one of the sectors targeted for major reform by the Government of Ecuador. The Government has placed a high priority on reducing income disparities between small-scale producers and large-scale plantation owners, exporters, and national and multinational companies. According to a study by the Central Bank of Ecuador, the banana sector faces a number of challenges, such as global overproduction; dependence on multinational trading companies for export; and lack of proper mechanisms to enforce the Banana Law. A key objective of the reform is to foster a more balanced relationship between the producer and the exporter (the two main stakeholders within the Ecuadorian banana industry) and between the plantation owner and the workers/labourers. Moreover, the reformed Banana Law places great emphasis on stabilizing the current use of banana land areas; enhancing productivity for small-scale producers, who suffer from lower average yields; and encouraging those farms, where bananas are unsuitable, to switch to other crops.

---

[7] Ecuadorian Executive Decree 818: Regulation to Stimulate and Control the Production and Commercialization of (Barraganete) Bananas and other *musaceas* for export.

The new Banana Law No 99-48, formally known as the Law of Production and Marketing of Banana Intended for Export, came into effect in July 2011 and consists of several components:

(a) Regulate the relationship between banana producers and exporters by establishing mutually agreed prices paid by exporters to producers, to be enforced through contracts;
(b) Formalize the relationship between plantation owners and hired workers and ensure improved wages and working conditions.
(c) Manage banana oversupply and control its impact on prices.
(d) Improve banana yields and productivity among small-scale producers.
(e) Enforce environmental regulations in relation to banana production.
(f) Pursue active trade policies to maintain current markets and expand into new ones.

4.1 Minimum price and producer/exporter contract enforcement

The new Banana Law establishes that the minimum price for bananas should be agreed through negotiations between the producers and exporters. In the absence of an accord, MAGAP and the Ministry of Foreign Trade will establish the minimum price. No banana fruit can be exported without a contract between the producer and exporter, and it is imperative that the minimum price be paid.

The Government of Ecuador periodically sets the minimum fair pre-shipment price that the banana growers should receive and the minimum FOB reference prices that the exporter has to declare. To establish the minimum price, MAGAP organizes bargaining tables between producers and exporters every three months, in order to reach a consensus. In the absence of an agreement, the Ministers of Agriculture and of Foreign Trade will establish prices on the basis of the average cost of national production, plus a profit. At the end of 2013, the official minimum price was USD 6 per box (18.5 kg of bananas) implemented under two seasonal prices: USD 6.75 per box for the high-price season (22 weeks of the year) and USD 5.40 for the low-price season (remaining 30 weeks of the year). Ecuador usually exports approximately 52 percent of its bananas during the first 22 weeks and 48 percent during the remaining 30 weeks (LACENA).

The law also requires the signing of contracts for the purchase of fruit with the support price. There are various types of contracts. The first is a contract in which the exporter buys all the fruit that is produced all year. The second is an area-based contract, specifying the area of the banana plantation on which the exporter lays claim to the harvested fruit. A third contract establishes the average number of weekly boxes to go to the exporter; these boxes may include price variations from 5 to 20 percent, based on the season. All contracts are valid for one year and obligate the exporter to purchase 100 percent of the production during the 52 weeks of the year. Failing this, the exporter is compelled to pay the producer the value of the unsold boxes. It also obliges exporters to pay for the boxes of fruit through the Interbank Payments System of the Central Bank of Ecuador.

Noncompliance by exporters is met with a fine equal to the value evaded. The contract also forces producers to register the fruit or be prevented from selling it. In Ecuador, the share of bananas sold under contracts has been increasing, although it remains below 100 percent. As of December 2013, of the 5.9 million boxes of bananas sold each week, approximately 5.7 million were sold under contract (LACENA).

The new Banana Law also establishes that the banana price includes a bargaining process whereby the exporters discuss lower fixed prices to be paid to producers in order to align FOB prices with those of competitors, while the producers will discuss the amounts to cover their cost of production, plus a reasonable profit. Producer groups, at a disadvantage in open-market price setting, can lobby the Government to tighten regulations and to force exporters to pay the official price. They also lobby against the costs that are transferred to the farmers, usually borne by the exporters. The producers propose minimum prices, taking into account their calculated production costs, a reasonable profit and a unified base salary for workers.[8] Among the challenges facing the Government of Ecuador relating to the implementation of a minimum price and the enforcement of contracts is the need to tighten regulations regarding seasonal exporters and ghost companies, so that they do not buy fruit only in the high season (January to March) and then disappear. This will affect those who have agreed to buy in the low season.

It is a challenge to incentivize the use of contracts in a country where the exporter is accustomed to operating in the spot market. Some exporters are reluctant to sign contracts with producers during the low-price season, while some producers are reluctant to sign contracts during the high-price season when they may receive higher spot prices. As a result, this often becomes a side-selling issue, when producers refuse to deliver under contracted prices at times when market prices are much higher. The Government of Ecuador monitors noncompliant exporters who sell outside of contracts and/or who thrust unjustified costs on to producers under the guise of technical assistance services.

4.1.1 Measures to encourage compliance with minimum prices and contracts

In April 2013, Ecuador created an automated system to control contracts and exports. This aims to enhance the country's capacity to monitor and regulate contacts between exporters and producers and to impose penalties for noncompliance.

An option that has been considered by the Ecuadorian Government has been the creation of a state-run exporter company to buy the bananas that are sold outside of contract in the hope of resolving the noncompliance issue (LACENA). Not all producers are supportive of the idea, however, with some expressing concern regarding delayed payments owing to bureaucratic inefficiencies. While the initiative has not been implemented, it has not been ruled out.

An additional measure that has been implemented to facilitate compliance

---

[8] At the end of 2013, producer groups proposed a minimum price of USD 7.50, while exporters settled for USD 5.15. Ultimately, the Ministry of Agriculture and the Ministry of Foreign Trade established the price of a box of bananas at USD 6.00 (LACENA).

with the minimum price system has been the creation of a stabilization fund for contributions from producers during the high-price season for use during the low-price season. In parallel, a line of credit has been extended to exporters to assist them to meet their contractual price arrangements with producers during times when market prices are low. The line of credit, administered by Ecuador's National Financial Corporation and overseen by MAGAP, compensates exporters by paying out the difference between the lower market price and the official minimum price.[9]

Responding to exporters' criticism that establishing a minimum price has put Ecuador at a competitive disadvantage in a globally unregulated banana value chain, the Ecuadorian Government has responded by using the tax code to sustain the sector's competitiveness. Ecuador, for example, has eliminated the special tax on bananas[10] and the special charge of USD 9 per 1 000 boxes, applied by the Ecuadorian Agency for Agriculture Quality Assurance (Agrocalidad) for the inspection performed on each 1 000 boxes of bananas exported.

4.2 Managing the oversupply and variability of bananas

As part of Ecuador's efforts to overhaul the banana sector, improve farm productivity and ensure compliance with official minimum price policy, the Government has undertaken a comprehensive census of the banana plantations in the country. MAGAP and Agrocalidad have validated the census data collected to date. The census is intended to assist in the optimization of use of land, water and resources through strategic zoning, and to better distinguish which plantations or agro-ecological areas are suitable for improved productivity and which are better suited for crop conversion. The plantation census is also critical in tackling the issue of abandonment of banana plantations, which is causing the spread of disease to neighbouring plantations, including those that are utilized only part-time during the high-price season.

According to data from 2012, Ecuador has a total of 165 132 ha of banana crops, managed by 12 000 farmers.[11] Approximately 25 percent of existing plantations do not have the required permits. There have been new plantings in several areas of the banana-producing regions, in particular the province of Santa Elena, a new region for banana expansion due to its drier weather and lower rainfall, which is suitable against BS disease.

Another way to manage the oversupply of bananas in the market is to implement a crop conversion plan for low-producing plantations located in unsuitable areas. Efforts are underway to convert some banana plantations into crops such as sugar cane, coffee or cocoa, oil palm and timber. Starting in 2012,

---

[9] The interest charged on the loan is set at 8.5 percent and loan repayments with interest are due during the high-price period (December or January). Exporters may apply for the loan until November and use the money to pay farmers within the eight days established by the Banana Law (LACENA).

[10] The special tax was 0.7 percent under the National Banana programme to transfer resources to Corpecuador for the rebuilding of roads, following the El Niño phenomenon.

[11] MAGAP - Communication to author.

the Government of Ecuador has targeted 15 000-18 000 banana plantations for crop conversion. A voluntary programme was initiated by MAGAP with respect to loans to producers who wish to convert from bananas to other crops. Under the programme, the Government will offer credit lines through the National Finance Corporation for the first four years, covering 100 percent of the production costs to farmers with less than 25 ha and 7 percent for additional fields (LACENA).

4.2.1 Expanding domestic demand for bananas

Domestic demand for the banana is low in Ecuador, since 95 percent of its production is exported. The Government is addressing the oversupply issue by creating new market outlets. One example is to encourage the use of banana flour as a potential substitute for wheat or to be mixed with the latter in small portions. Another concept is to introduce the banana fruit into school lunch programmes. According to the Ministry of Education, the Government serves breakfast to 1.7 million students under the school breakfast programme, covering 1 600 educational units and benefitting students between 4 and 12 years of age (LACENA). Adding banana to the breakfast menu will require at least 145 000 boxes of bananas a day for distribution among students, or 2.9 million boxes of fruit per month if the initiative is put into effect. MAGAP is also studying the possibility of extending banana consumption to military institutions and public hospitals.

4.3 Support to farmers with regard to productivity

Officially, the plan to upgrade banana productivity for small-scale farmers is based on four types of support interventions: (i) strengthening associations and businesses; (ii) technical assistance; (iii) financing through loans; and (iv) research. In addressing the issue of low productivity on small farms, the Ministry of Agriculture recognizes that not all small plantations are located in suitable production areas and that some substitution with other crops may be required for some farms.[12] Moreover, access to technology and improvement of management techniques hinge on stable incomes for small producers. Stabilizing small producers' incomes is being addressed, in part, by the Government of Ecuador through minimum price and contract enforcement. The Government has also implemented a measure to encourage the formation of producer associations and to facilitate alternative marketing channels.

Small farmers have not yet mastered common management techniques, such as sound fertilization programmes. The objective of training programmes to build the managerial capacity of farmers to improve banana productivity is being considered.

4.4 Social protection and the policy on the rights of workers

An important pillar of the Banana Law is to formalize the status of banana workers within plantations; ensure improved working conditions through formal contracts; and enforce compliance with the minimum wage policy, social security

---

[12] Personal communication by the author with Ministry officials.

and health insurance benefits for workers. This is an important social policy, since almost 10 percent of the population derives its economic livelihood directly or indirectly from the banana industry. To meet this social policy objective, the Government of Ecuador is registering all producers to ensure that they comply with their employer obligations by ensuring that all workers have a contract, enjoy social security benefits, and receive at least the minimum and overtime wages.

Since the passage of the new Banana Law in July 2011, it was hoped that all banana plantations would be registered by December 2013 and that the state of workers would be sanctioned through regular contracts. To set the minimum price to the producer, the Government authorities need to establish the production cost, according to plantation size and volume of exports, and then calculate the profits and taxes to be added. The Government also monitors employers to ensure that they pay the minimum salary and the payroll tax. In 2013, the minimum monthly wage in Ecuador stood at USD 437 (LACENA). The obligation for producers to sell only through contracts has compelled more than 3 700 of the 4 000 producers, who are not registered with the Ministry of Agriculture, to legitimize their activities, including meeting employer obligations to the social security system.

4.5 Environmental regulations

Among the priorities of the Government of Ecuador with regard to the banana sector is the need to develop an adaptation strategy to improve the phytosanitary practices within the sector. The legal framework for the new phytosanitary strategy is embodied within the reformed Banana Law. Under this law, farms of up to 20 ha require registration cards, while larger plantations require environmental permits or licences. These cards are issued after MAGAP has determined that risks to the health of nearby populations and workers on the plantations have been minimized. Other requirements are remediation strategies as a result of emergency events on the banana plantations (e.g. floods, disease outbreaks). Given that environmental compliance varies significantly from one banana-producing region to another, the objective is to harmonize compliance across the provinces. The environmental performance for Los Rios, for example, is good since, in terms of indicators, 47 percent of the farms have registered and 37 percent are in the process of doing so. On the other hand, the banana provinces of El Oro and Guayas have much lower rates of compliance with environmental regulations. According to the Ministry of the Environment, only 2 percent of the banana plantations in the Guayas region are appropriately licensed and 4 percent are in the process of being licensed. In El Oro, the figures are 1 percent and 9 percent, respectively (LACENA).

The Government of Ecuador also regulates and sets limits to aerial chemical spraying. The aerial applications are restricted to within 100 metres of the river banks, and by the same distance from village schools and health centres. For the manual application of agrochemicals, the buffer zone is 50 metres from these specific areas.

The Government is now implementing a broader environmental tax policy in the form of a green tax to influence consumer behaviour, reduce vehicular pollution and lower the use of plastic bottles. Large producers, as well as exporters, are required to pay 2 percent of income tax for each box for banana fruit under the Law on Environmental Development and Optimization of the State Revenue. The tax is levied over and above the official price and not over and above production costs. In addition the tax package includes a tariff levied on the land used for banana crops.[13]

4.6 Trade policy: diversifying export markets

Since most bananas produced in Ecuador are exported, there is a need to maintain existing markets and expand new ones, which is key to the viability of the sector. An active trade policy, therefore, is a critical element in Ecuador's banana strategy. One of the mechanisms to facilitate market access is the negotiation and conclusion of trade agreements. In 2014, Ecuador formally reinitiated negotiations for a trade agreement with the EU. These negotiations started just after EU cancelled the Generalized System of Preferences (GSP) for Ecuador as the latter, since 2010, had risen to an upper-middle-income status.[14] The EU decision represented a significant loss to Ecuador's trade with the EU, since nine of Ecuador's main exports to Europe (excluding bananas, which are precluded from GSP) are subject to preferential tariffs under the GSP Plus. Since 2014, the EU has imposed tariffs on Ecuadorian products, averaging 24 percent compared to 0 percent under GSP Plus (LACENA). This reversal of preferential status may have added greater impetus for Ecuador to reach a new trade agreement with the EU.

Ecuador's negotiation with the EU is to ascertain a trade agreement that can improve the market access for its key exports and, at the same time, account for the country's objectives towards development and the protection of its food sovereignty. The EU, in turn, is seeking to secure manufacturing and service sector contracts and concessions from Ecuador for European firms through government procurement bids, in exchange for tariff concessions to Ecuador. During the first round of negotiations, held in Brussels in January 2014, Ecuador presented its list of products (petrochemicals, bananas, coffee, cocoa, shrimp, flowers and tuna) for which it seeks lower tariffs from the EU. It also presented its import exemption list (milk, chicken, sausage, meat and processed foods) from trade liberalization on the grounds of food sovereignty. This suggests that negotiations are likely to be a drawn-out process.

Ecuador is also seeking trade agreements with other countries to improve its export diversification strategy. These include agreements with Latin American countries (e.g. Chile), Turkey, the Middle East and Eastern Europe.

5. Discussion and general conclusions

5.1 Economic sustainability

The banana sector is of vital economic importance to Ecuador, owing to the size of the sector and from which the large share of the population (10 percent)

---

[13] In 2012, the green tax generated USD 360 million, of which USD 200 million was allocated to improve the quality of fuel, while the balance was earmarked for the health sector (LACENA).

[14] The country's GDP is above 1 percent of global GDP, according to the World Bank's classification.

derives its economic livelihood. Its economic stability, vitality and sustainability are of strategic importance. This section discusses the sustainability challenges facing Ecuador's banana industry and the complex challenges of climate change.

Economic sustainability is gained through the optimal management of supply, a continuous ability to meet global demand, and the fair distribution of benefits to key stakeholders, especially with regard to small-scale producers and workers, all of which affect income stability. It also derives from the constant ability to make the investments that are required to enhance yields and productivity.

Since 2011, the Government of Ecuador has embarked on a major restructure of its banana industry, putting into place a policy that not only addresses supply and demand challenges, but also establishes a fairer distribution of returns by key value chain stakeholders (workers, plantations owners (growers) and exporters). Since the banana sector is tightly integrated into the global value chain, the banana policy is only applicable within Ecuador. Outside its borders, Ecuador has pursued ways in which to tackle the dynamics of changing demands, competition, oversupply and growing requirements for standards and norms by buyers on behalf of consumers. As trade is critical for the economy of the banana sector, Ecuador has followed various initiatives to diversify its export markets and maintain its current markets through trade agreements, such as with the EU, and other mechanisms. The economic sustainability of the banana sector in Ecuador hinges on meeting the following four challenges:

1. ***Stabilize incomes for small-scale producers and workers through a fairer distribution of benefits along the value chain***. This is being pursued through the enactment of the minimum price for bananas that is enforced through contracts. It is an important element of banana policy and a challenging one, since it hinges on reconciling the opposing economic interests of exporters and producers on the one hand and producers and workers on the other. In both cases, the Government is forced to play the arbiter role and ensure a social outcome by intervening in a considerably competitive market with uneven bargaining/negotiating power among stakeholders (small-scale producers may be more inadequate vis-à-vis exporters, but stronger vis-à-vis workers). In this case, the Government will go beyond its power to deploy a variety of incentives (e.g. lines of credits, stabilization funds) to motivate maximum collaboration by stakeholders, in order to stabilize and maintain incomes over time.

2. ***Rationalize banana land use and regulate new banana plantations***. To prevent unwarranted land expansion, the Government of Ecuador should ensure improved supply management (avoiding the over-supply of bananas). The strategy should also make it easier to identify the plantations that are suitable for productivity-enhanced measures and those that can be converted to alternative use. These measures are part of an overall strategy that includes a survey and the registration of all banana plantations, in order to facilitate social and environmental regulations and enable better management of the requirements relating to minimum price and contract enforcement.

3. ***Improve productivity through a programme that disseminates improved techniques, fertilization programmes and better management of pest control***. This includes approved control methods for organic farming. Most of these support measures require producers to form associations to receive technical assistance and management capacity-building support. This is not a significant challenge, since the marketing of bananas often requires producers to organize and work in groups, especially when banana certification is required. Such measures, however, require sufficient capacity in applied research, technology adaptation and extension. An evaluation of the country's current capacity in research, technology development and extension is required to determine critical needs, identify gaps and establish an appropriate action programme.

4. ***Increase demand opportunities to better control supply/demand balances, and, hence, stabilize prices***. This includes maintaining current market access to the EU and expanding exports to emerging markets with rising middle-class consumers. Another element of this strategy is to diversify the banana value chain by encouraging other banana uses (e.g. banana flour) or encouraging domestic consumption (institutional buyers, such as schools, hospitals and the military).

If implemented in an integrated way, these four measures should contribute to (i) an improvement in yields; (ii) lower production costs; and (iii) stability and better supply/demand balances. These, in turn, will ensure improved and more stable incomes for producers and workers - the *sine qua non* for long-term economic viability of the banana industry. To achieve full sustainability, however, the salient environmental and social dimensions relating to the banana sector in Ecuador also should be addressed.

5.2 Environmental sustainability: pests and the use of pesticides

Bananas are among the most import food crops in the world, but they come at a huge cost as they require large amounts of agrochemicals, which have significant negative environmental and health side effects. Chemical applications are known to harm the health of unprotected workers and the inhabitants surrounding the plantations; they also contaminate nearby water supplies, often with long-lasting impacts (FAO, 2003).

The most important challenge is how to mitigate and minimize these side effects. A combination of strict regulations, economic incentives for improved technologies, and broadening the use of nonchemical methods must all be included in a strategy to meet this challenge.

It is important to devise a national regulatory strategy relating to the use of pesticides - providing evidence of minimizing the negative effects of pesticides - and the preservation of the economic viability of banana production. This will be a challenge, however. Possible measures to consider are to:

(a) enact strict regulations for aerial chemical spraying, based on evidence and quantified impacts (if available);
(b) introduce and promote the adoption of improved technologies that are known to minimize the risks, such as the use of GSP technology by spray jets and other precision delivery techniques;
(c) broaden the use of integrated pest management techniques by disseminating a protocol for the implementation of the Integrated Pest Management (IPM), supported by producer training and economic incentives; and;
(d) adopt a clear zoning strategy and the delineation of no-go zones for banana production, on the basis of environmental risk assessments.

In addition to the regulation of chemical applications, there are a number of complementary measures or production techniques that can contribute to reducing environmental side effects. Among these are the adoption of improved water management techniques; fertigation; frequent replanting of banana plants to avoid heavy spraying; and, when economically viable, organic production.

Organic production offers additional challenges to combat major diseases, such as BS, as organic production requires more intensive management and knowledge. It also requires a more solid research base to develop nonchemical pest control methods and introduce protocols to monitor organic inputs, thus ensuring that protected areas are dedicated to organic bananas with no risk of contamination from chemical use by adjoining plantations. These proposals require strong public support and solid policy measures. The creation of a national umbrella organization for organic producers can be a key institutional reform that would greatly facilitate these processes. The organization would liaise between organic producers, the Government and other private sector stakeholders, as well as articulate the interests and needs of organic producers and contribute to the formulation of policy and/or supporting measures.

Small-scale farmers also apply nonchemical methods against pests, such as removing old infested leaves, intercropping with disease-resistant crops and planting in partial shade areas, thus reducing the instance of disease (Ploetz, 2001). Other nonchemical techniques for controlling BS are to use plastic sleeves that separate the hands on each bunch during the growing period; reduce the amount of scarred fruit and rejects; and accelerate maturity before the harvest (FAO, 2003). IPM techniques rely on a mixture of mechanical, biological and chemical means to control pests. As such, IPM seeks not to eradicate pests, but to limit their presence to an economically manageable level. IPM also carefully manages fertilization so as to limit the contamination of surface and underground water (Merchán Vargas, 2002). The most successful widespread application of IPM has been in the Dominican Republic, where its application has significantly encouraged the widespread adoption of organic banana production in the country. As a result, the Dominican Republic is now the topmost producer and exporter in this niche banana market (Roquigny *et al*., 2008).

5.2.1 *The aggravating impact of climate change*

In Ecuador, climate change translates largely into rising temperatures, changes in frequency and intensity of extreme events (droughts, floods), the retreat of glaciers, and the consequent changes to the hydrological regime. According to Machovina (2013), the projected impact of climate change and variability on banana suitability remain broadly favourable through 2070. The same study reported that current land suitability for banana in Central and Latin America will have changed significantly by 2060, with the exception of Ecuador. Approximately 41 percent of land that is currently not suitable for the growing of banana will become suitable; 58 percent of currently suitable land will become less so; and 39 percent will experience no change. Relative to Ecuador, climate change assessments in other major banana-producing countries show that, broadly, Central America and the Philippines will be more adversely affected than Ecuador. New favourable areas for bananas will include southern Brazil (São Paulo to Pôrto Alegre) and areas within the southern noncoastal region of China (within Guangdong).

For Ecuador, the projected scenario is favourable in terms of the overall suitability for banana, although it will be complicated due to the biotic effects and impacts on diseases and the dynamics of pests. While more information is needed to link increased temperatures to pest dynamics and the length of their reproductive life cycle, preliminary indications suggest that banana pests, such as weevils and nematodes, may increase, become more aggressive and create more damage.

Climate change in the medium to long term will likely require adjustments in certain banana production practices. The increased variability in weather from one year to the next and the greater frequency of moderate and extreme weather events represent added challenges for scientists, growers, marketers and banana export companies. In general terms, higher temperatures are less favourable for BS, but higher rainfall and humidity are suitable for it. Higher rainfall will likely increase flood risks, while reduced glacial buffers, coupled with higher temperatures, will challenge existing water management systems, increase drought stress and may increase plant susceptibility to Panama disease.

5.3 Social sustainability

Banana fruit is a highly efficient value chain, with a significant market value of over USD 17 billion, globally, and more than USD 2 billion of value added for Ecuador. Nevertheless, the sector is notorious for unfair labour treatment and extremely low returns to workers. In addition to the environmental cost of pesticides, social inequity has plagued the sector since the beginning of the twentieth century. Banana production is labour-intensive, with labour costs accounting for 40 to 50 percent of total production costs; consequently, reducing the wage bill has long been one of the prime objectives for cost minimization by plantations owners (nationals and MNCs).

The issue is not new. Concerns for workers' conditions and the environmental costs from pesticides have been widely advertised by NGOs (mostly European) since the 1990s. This has placed pressure on retailers to use their rising market power to correct these externalities. The response has been the emergence of niche markets, such as organic and Fairtrade Certification bananas that incorporate some measures of labour protection. Retailers also have established their own voluntary environmental or social norms, but to little effect, given that they were embroiled in a conflict of interest between pushing for strong social and environmental norms and preventing these from resulting in higher costs and lower margins. Ultimately, the retail sector has outsourced verification and compliance of its own norms (GlobalGAP, originally known as the EurepGAP) to third-party certification bodies that work on their behalf as their main clients (since the retailers select the certification body with which to work). While Fairtrade Certification bananas may generate slightly higher prices for plantation owners and workers, evidence to date has shown that neither organic nor Fairtrade Certification have had any significant impact on the vast majority of banana workers in developing countries due to the continued small share of fair trade and organic bananas in the total market. At best, these niche markets have had a marginally positive effect, since they continue to go through the same marketing channels as conventional bananas and are subject to the same market and price-setting conditions imposed by the concentrated retail sector. This has resulted in a substantially distorted distribution of value in favour of the retailer (35-40 percent), with only a very small share flowing to banana workers (below 3 percent).

A detailed study that documents the treatment of banana employees in Ecuador was issued by Human Rights Watch in 2002. Although somewhat dated, the study represents one of the most detailed analysis relating to the issue. Since Ecuador enacted its new, ambitious Banana Law in 2011, however, the situation for employees and the extent of child labour - also an issue - may have changed. The law requires that all plantation owners register their employees with social security and, thus, formalize employment contracts. Moreover, the Government of Ecuador has insisted on adhering to the minimum wage and providing other benefits (e.g. social security and health) for all workers. To date, however, no formal or independent evaluation has been undertaken of current conditions and there is no rigorous method on how to gauge whether or not there has been an improvement since the Human Rights Watch study. To fully assess current working conditions, it is necessary to include the prevailing national daily minimum wage for a banana worker, the basic monthly cost (in US dollars) of a basket of food, as well as other basic household needs in rural Ecuador. These facts would determine whether or not a household of two or four can subsist on the minimum wage.

To ensure fair wages for workers, it is important to encourage and protect their right to form unions and engage in transparent wage negotiations with plantation owners. While owners are now subject to registering their employees and providing formal contracts under the Banana Law, it is equally important that these measures safeguard the right to form unions in adherence to the Minimum Wage Convention of the International Labour Organization.

The conditions to allow banana workers to organize themselves to extract higher wages have been stymied in Ecuador for a long time, as documented in the Human Rights Watch study. Previously, when Ecuador ignored the theory and literature relating to labour laws, employers were able to maintain a permanent temporary workforce on the plantations. Workers were engaged through extendable short-term contracts so that employers could bypass the labour laws that related only to those workers under formal contracts. Employers were within the law to enable them to block organized unions simply by dismissing workers and paying a small fee. Furthermore, banana plantation owners preferred to rotate the workforce that handled dangerous chemicals by issuing short-term contracts rather than improve working conditions or provide protection against pesticides. It is not a revelation, therefore, that union activity could not take place under these conditions. In fact, the Human Rights Watch study was able to detect that only a very small fraction of workers did form labour unions.[15] It is essential, therefore, that these employment practices be reformed as a prerequisite for social sustainability.

5.4 Improved governance for a sustainable banana industry

To enhance the sustainability of the banana industry - especially with regard to the use of pesticides and minimizing the risks involved - requires innovation with regard to governance. Innovation can be in the form of regulatory institutions and policies, incentives, or information and technology, such that they can directly influence producers or achieve impacts indirectly through the decision-making of consumers, retailers and processors. It is important that there is consensus on the governance mechanisms and institutional arrangements that can best support such interventions.

Governance, in its complexity, must be based on a multidimensional approach that considers political processes (politics), institutional structures (polity) and policy content (policy) (Lange *et al*., 2013). In analysing governance along the commodity value chain, it is important to recognize the degree of influence certain actors hold along the chain to understand their roles in influencing agricultural production. In addition, complementary institutions, incentives and information are often combined, while multistakeholder collaboration between different groups of stakeholders is desirable.

In the case of the banana, multiple forms of governance operating at different levels (local, national and international) are required to ensure the transition to more environmentally sustainable systems from the social dimension in terms of equitable distribution of benefits; protection of workers' rights; and affected communities' health and economic wellbeing. From the environmental dimension, it is essential to minimize the risks of pesticides; confront the rising challenges of climate change and the consequent water resource issues; and manage extreme weather events.

At the national level, the banana policy serves as the framework to improve social equity and workers' rights. An essential element is a mechanism to monitor

---

[15] The study found only five successfully organized groups out of more than 5 000 registered banana plantations in Ecuador and only approximately 1 650 of the more or less 120 000-148 000 banana workers are affiliated with workers' organizations - approximately 1 percent of the workforce.

implementation and the compliance with labour rights and regulations that relate to social impact. It is necessary to develop the capacity to negotiate, within a multistakeholder framework, the preferred social outcomes that should be implemented and enforced. In terms of the environment, current laws will need to be enhanced and their enforcement should be strengthened. Critical to the implementation of environmental policy is research and the technical capacity to undertake the evidence-based environmental assessments that are necessary for regulation and its implementation.

With regard to climate change, sound governance is only now starting to take place, although the structures and mechanisms that are necessary to address the priorities required to tackle the impact of climate change are not yet sufficiently adequate. Since further evidence is essential regarding the potential implications of climate change on diseases, it is necessary to strengthen a country's agricultural research. The development and testing of pest-resistant clones against current and emerging threats is crucial - especially in the light of their close links to the impacts of climate change. This requires a strengthening of global research networks and institutions that specialize in the banana and in climate change. The need to develop more robust weather information, monitoring and recording is also critical to the adaptation and mitigation of climate change.

On the global level, much can be done to ensure a speedier transition towards the sustainable management of banana value chains. Existing governance structures along the global banana value chain need impetus to achieve more sustainable practices, including strong and enforceable safeguards to minimize the environmental damage caused by the substantial application of agrochemicals. Improved governance can be achieved through information and raising consumer awareness that inexpensive bananas are not sustainable and that the true environmental and social cost of their production requires serious alternatives. New ways should be sought to internalize the full cost of banana production, including the cost to the environment, which is currently externalized and is a missing component in the economics of production, distribution and consumption. Such outcomes - to the extent that they can translate to higher prices - would lower overall demand, paving the way for substitutions with other food products. This must be the price to pay if it is agreed, on a global basis, that a sustainable environmental and socially equitable banana system is a goal worth achieving.

©FAO/Aziz Elbehri

CHAPTER 3:

CLIMATE CHANGE IN ECUADOR AND ITS IMPACT ON BANANA CROPS: AN OVERVIEW

David Skully* and Aziz Elbehri**

---

* Independent consultant, FAO. Pedro Sousa provided research assistance for this study

** Trade and Markets Division, Department of Economic and Social Development, Food and Agriculture Organization of the United Nations (FAO), Rome

1. Climate change and global trends

The Intergovernmental Panel on Climate Change (IPCC) released its Fifth Assessment Report in 2014 and provides an updated evaluation of climate change trends (IPCC, 2014a; IPCC, 2014b). The IPCC forecasts an increase of 3.4°C in the average global temperature for the period 2080-2099, relative to 1980-1999, if mitigation efforts against global warming remain the same as today. With more concerted efforts, the increase could be 2.4°C.[16] Forecasting becomes less precise within smaller areas, although temperatures become less the nearer the Equator and more the closer to the North and South Poles.[17] The interiors of the world's continents, which are the most distant regions from the moderating influence of the oceans, tend to have the highest temperatures. The surface of the ocean warms less than does land surface. Finally, the increase in temperature at higher altitudes is greater. While this does not have a direct effect on the banana, the seasonal discharge of water from small glaciers and snow fields to river basins could alter and challenge existing water management systems in banana growing areas.

2. Climate change in the Amazon region

2.1 Temperature

Ecuador belongs to a region of the Amazon which comprises South America, north at 20° South.[18] The average predicted increase for this region of the Amazon for 2080-2099 (relative to 1980-99 temperatures) is 3.3°C (see Figure 13, wherein the bar in the middle represents the mean forecast). Half of the climate models included in the IPCC assessment predict increases within the ranges of 2.6°C and 3.7°C, indicated by the shaded box in Figure1. The lowest and highest forecasts are 1.8°C and 5.1°C, respectively, represented by the lines extending below and above the box.

IPCC considers that the chance of a change in the projected temperature at the end of the twenty-first century will be at least 66 percent correct. Future temperatures will depend, in part, on global mitigation efforts and known or unknown physical factors. In the short term, the temperature relating to the next two decades is likely to increase by at least 0.2°C each decade.

2.2. Tropical cyclones

Tropical cyclones are a hazard to the production of bananas. Ecuador is free of tropical cyclones, as is the west coast of South America - an advantage

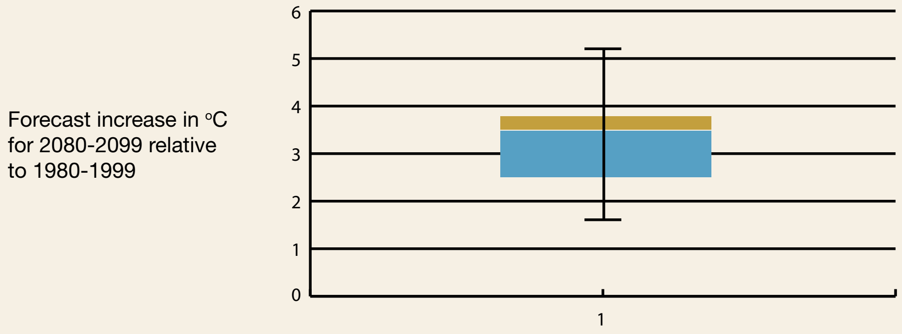
---

[16] The forecast ranges are: 2.0°C to 5.4°C and 1.4°C to 3.8°C.

[17] The Equator experiences minimum seasonality: the amount of daylight (from sunrise to sunset) in Guayaquil (2°C 11'S) ranges from 12:00 hours on 20 June to 12:14 hours on 21 December, a difference of 14 minutes. Above the Arctic Circle (66°C 34'N) the annual variation in daylight is 24 hours, from 0 minutes in the middle of the winter to 24 hours in the middle of the summer

[18] The 200S latitude crosses approximately 200 km south of the border between Chile and Peru and includes most of Bolivia and Brazil, north of Belo Horizonte

Figure 13 IPCC temperature forecasts for Amazonia



Source: IPCC (2007). P. 894

compared to Central America, the Caribbean and the Philippines which are exposed to tropical storms and cyclones.

Whether or not global climate change will increase the risk of tropical cyclones is a topic of ongoing popular and scientific debate. With regard to tropical cyclones, it is difficult to distinguish the weather from the climate, where climate is the long-term normal pattern of the weather and the weather is the hour-to-hour, day-to-day and year-to-year realization of the climate. Weather varies around the climate average. While temperature and the concentration of carbon dioxide (CO_2) have had a long history of research, the accuracy of tropical storm observations only extends as far back as a few decades. Observations have, so far, been limited to major storms that have struck populated areas and the strength of the storms has not been consistently measured. As a result, there is a short series of observations relating to the relatively infrequent and variable phenomenon of cyclones. The number of recent Category 5 (strong) tropical cyclones (e.g. Mitch in 1998; Katrina, Rita, Wilma and Typhoon Pablo (Bopha) in 2012) has established the view that tropical storms are growing stronger and more frequent.[19] The data, however, do not support this, since the recent spate of destructive storms is not inconsistent with the longer-term frequency of tropical cyclones (Solow and Moore, 2002; Peduzzi *et al*., 2012).

Looking forward, physical climate models predict that higher global temperatures may reduce the probability of tropical cyclones. Cyclones that do develop, however, will be - on average - stronger.[20]

---

[19] Hurricane Sandy's impact on the East Coast of the United States in 2012 added to the perception of a stronger trend but Sandy was, in fact, a Category 2 storm and, thus, was relatively weak and well within the normal range of tropical storms for the North Atlantic. It was highly destructive because its path crossed densely developed coastal areas. There is an upward trend in the economic losses caused by tropical storms but this is due, primarily, to more development in vulnerable coastal areas rather than the increasing severity of the storms. Higher sea levels also contribute to the risk of flood damage associated with tropical storms.

[20] The definitive assessment is IPCC (2012):158-163. See also Knutson *et al*. (2010) and World Bank (2013):74-75, and 93-94.

2.3 El Niño

The relationship between higher global temperatures and the El Niño Southern Oscillation (ENSO) is not clear. The following is the conclusion of a recent review of the literature on ENSO and climate change.

> "Despite considerable progress in our understanding of the impact of climate change on many of the processes that contribute to El Niño variability, it is not yet possible to say whether ENSO activity will be enhanced or damped, or if the frequency of events will change" (Collins *et al*., 2010:391.)

The IPCC (2012) report on the risks of extreme events supports the conclusion that ENSO may change with higher temperatures. The results of climate model simulations, however, are so varied with regard to ENSO that it is not possible to conclude how it will change.[21] At first glance, the conclusions appear to be incomplete and provide little positive information. There is, nevertheless, an important positive finding in that there is increasing uncertainty and that the expected range of future ENSO activity will be wider than its former range. Despite this, there is no reason to suggest that future average activity will be greater or less than the current average. Figure 14 illustrates one way in which to illustrate an increase in uncertainty. It plots two normal probability density functions (bell curves) that have the same mean but different variances. The shorter, wider distribution has twice the variance of the taller, narrower one. The wider distribution has longer and fatter tails.

The study by Pindyck (2011) contends that climate change analyses generally fail to emphasize sufficiently that the tails of the future distribution of the climate are becoming fatter. The IPCC grants its highest confidence to results for which there is a high level of agreement among climate models. When model results are widely dispersed - as with those of ENSO - there is less confidence and, therefore, less attention is given to the outcomes. Extreme events, however, are becoming more probable but will be less frequent than they used to be. Pindyck (2011) argues that the fattening of the tails should cause individuals and governments to consider how to ensure against the increased risk of extreme climate changes.

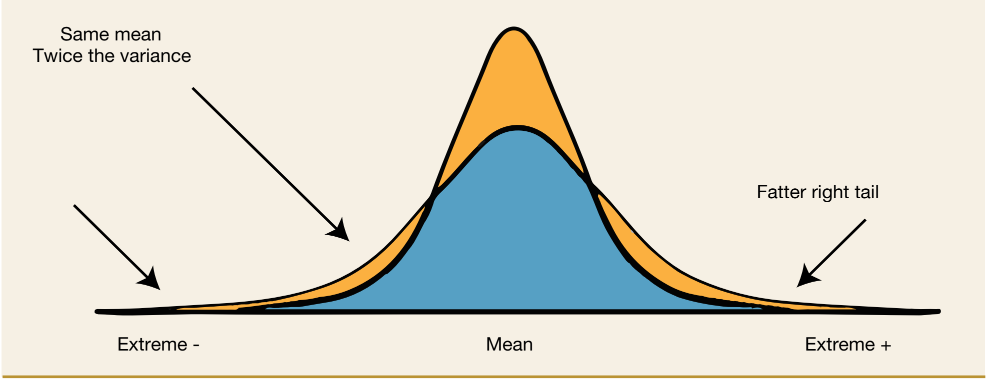
3. The increasing impact of climate change on Ecuador

Ecuador's climatic conditions are influenced by its location on the Equator and the presence of the Andes mountain range, the Amazon and the Pacific Ocean. The combined effects lead to marked spatial and seasonal climate variations in the different natural regions of the country. According to Ecuador's

---

[21] ENSO is particularly difficult to model because it is a composition of several oscillating systems. Katz (2002) explains the discovery of the Walker Circulation relating to how the analysis of ENSO required new statistical methods. ENSO modeling is an active area of research, with recent key contributions including Emile-Geay *et al*. (2013a, b) and Li *et al*. (2013).

Figure 14 Increased uncertainty



Source: IPCC (2007). Pg. 894

National Environment Policy, the country has experienced sustained increases in temperature; changes in the frequency and intensity of extreme events (droughts, floods); changes in the hydrological regime,; and the retreat of glaciers.

The National Institute of Meteorology and Hydrology (INAMHI) in Ecuador monitored the national temperatures in 1998, 2002 and 2007 and reported increases in the minimum, maximum and average temperatures around the country, with some exceptions in certain geographical areas. The magnitude of temperature change varied according to local climate characteristics, such as the proximity to the sea, topography, among others. In terms of rain, the INAMHI reported that the annual amount of precipitation between 1960 and 2006 has varied between regions, with a tendency towards an increase in areas of the Sierra (mountain areas) and the coast, especially the coastal areas of the provinces of El Oro, Guayas, Santa Elena and Manabí. Limited information exists, however, for the Amazon region. On average, annual precipitation increased by 33 percent in the coastal region and by 8 percent in the inter-Andean region.

In recent years, extreme events have intensified, with floods and droughts lasting for short and long periods and causing economic and environmental damage. A study by INAMHI[22] revealed a propensity for an increased number of consecutive dry days in the central regions and persistent periods of rain in the northern Ecuadorian coast and the foothills of the Andes. The study also showed that the area of Manabí is prone to a shortage and an excess of precipitation (INAMHI).

Annual loss in economic terms, in relation to climate-related events, highlights the vulnerability of Ecuador to climate change. In the past decade, Ecuador has suffered an economic loss of more than USD 4 billion from droughts alone. This high exposure has increased the vulnerability of key economic sectors,

---

[22] The study "Climate Information for Hydrometeorological Hazards in the Coastal Provinces of Ecuador" applied RClimDex software and calculated various climate indices over 72 seasons (unpublished).

such as agriculture, water resources, fisheries, infrastructure and tourism. The effects of climate change, including the increased frequency and intensity of El Niño and La Niña, combined with deep pockets of food insecurity and poverty require Ecuador to develop sound planning and replicable implementation models to address the threats of climate change. Although Ecuador is an oil exporting country, there remain large disparities in living conditions and access to opportunities.

3.1 The retreat of glaciers

The retreat of glaciers in recent years has been significant - 20 to 30 percent loss of ice mass in the last 30 years. High mountain agro-ecosystems in Ecuador are exposed to cyclical drought; thus, glacier runoff is critical for providing mountain communities with reliable water sources and sustainable livelihoods. Likewise, coastal and estuarine ecosystems along the Pacific Coast and the Guayas River Estuary are especially exposed to rising sea levels, as are the settlements in the low-lying coastal areas. These zones are affected by increased coastal erosion, tidal surges and flooding. They are particularly prone to salt water intrusion, and aquifiers are especially vulnerable to changes in groundwater quality.

Over the past few years, increasing social conflict surrounding water resources and watershed management in Ecuador have led to a growing public debate surrounding the need for policy reform in the water resources sector. The current baseline in Ecuador is characterized by:

i. a dispersed water governance arrangement, leading to increased competition and conflict over scarce resources;
ii. lack of coherence between national climate information and local/regional end users, as most water-use permits are issued, regardless of the state of water resources;
iii. lack of financial and technical resources for community-based users to improve their adaptive capacities or implement innovative water management approaches; and
iv. insufficient generation of knowledge and its dissemination relating to climate-related risks or threats.

3.2 The threat of climate change to Ecuador's agriculture

Unlike countries at middle latitudes, Ecuador has two seasons a year: a rainy and a dry season. Increasingly, Ecuador suffers from a range of natural disasters, including floods, droughts, earthquakes and volcanic eruptions. Reoccurring floods and droughts are also intensifying in severity.

Two climate-linked challenges face Ecuador's agriculture. The first is having water in adequate quantity and quality for the production and post-harvest processes, such as washing, which requires significant amounts of water. Banana cultivation depends substantially on water irrigation due to the fact that the precipitation rate of the production area does not meet the requirements of the crop. This also requires policy proposals on how best to handle the distribution of this key resource in times of shortage and crises that can arise from a decrease in rainfall in areas from where the irrigation water originates. The second challenge is the presence of the Mancha Roja, a red-spotting disease that reduces the commercial value of the fruit. It is feared that changes in the climate are increasing the severity of the disease. For the time being, however, the best option to tackle the disease is through good agricultural practices or integrated production and pest management methods. Overall, there is a need to create eco-efficient agriculture; that is, to build environmentally sustainable production systems that are equitable to all stakeholders in the supply chain.

3.3 GHG mitigation in Ecuador

Although Ecuador's contribution to GHG emissions is marginal, it is committed to lowering GHG emissions and to address climate change adaptation. In the Constitution of the Republic of Ecuador, Article 414 states that "the State shall take appropriate and transverse measures to mitigate climate change by limiting emissions of greenhouse gases from deforestation and atmospheric pollution; take measures for the conservation of forests and vegetation, and protect the population at risk". Ecuador's National Plan for Good Living states, as Objective 4, "to guarantee the rights of nature and promote a healthy and sustainable environment". Ecuador has developed a National Climate Change Strategy stipulating political and technical commitments to environmental stewardship through sustainable processes and innovative initiatives. Ecuador has also recognized the need to build resilience and mitigate the risks associated with the adverse effects of climate change and variability, natural disasters and other shocks. It intends to enhance the adaptive capacity of vulnerable communities and strengthen its capacities for emergency preparedness and response, including food logistics and storage. Ecuador is also faced with the increased challenge to regulate the supply of aquatic ecosystems.

4. Implications of climate change on Ecuador's bananas

4.1 Impacts outside Ecuador

4.1.1 Other banana producing countries

Two recent studies have used IPCC climate forecasts to calculate how global climate change is likely to alter the suitability of banana production globally: Ramirez, *et al.* (2011) and Van den Bergh *et al.* (2010). Their analyses indicate that climate change generally makes the world a less suitable place for banana production. Warmer average temperatures increase the risk of heat stress and damage to banana plants in several major banana-producing areas: the Caribbean Islands, Central America, the Atlantic coast of Colombia and Venezuela, West Africa and Southeast Asia.

Lower forecast precipitation is an additional limiting factor to banana production in Central America and the Philippines. This reduction in rainfall is directly related to the more El Niño-like climate discussed below. The increased rainfall in the eastern equatorial Pacific (most of it over the ocean) means less rainfall in the western equatorial Pacific (the Philippines) and in Mexico and Central

America.[23] Thus, the two major competitors to Ecuador in exporting bananas - Central America and the Philippines - are adversely affected by forecast climate change and proportionately more so than Ecuador.

Higher temperatures improve the suitability of banana production in the subtropics, defined approximately as between 20° and 30° North and South, respectively. In this zone, the current limiting factor to banana production is the high risk of damage at cool temperatures (minima below 10°C and averages below 16°C). Higher mean minimum temperatures reduce this risk and increase banana suitability. Van den Bergh *et al*. (2010) calculate that suitability improves greatly in southern Brazil (São Paulo to Pôrto Alegre) and in southern non-coastal China (interior Guangdong). Domestic demand is likely to absorb any increase in Chinese production, but Brazil may have an increased exportable surplus.

Higher temperatures will increase the maximum altitude at which bananas can be produced. As highland banana production is generally for local and household consumption rather than for export, this is unlikely to be an important direct influence on banana trade, but it could have a major impact on food security in areas where bananas and plantains play a major dietary role.

4.1.2 Disease

Global climate change will influence the incidence and severity of plant disease. The two major diseases of bananas are Black Sigatoka (*Mycosphaerella fijiensis*) (BS) and Panana disease (*Fusarium oxysporum f. sp. cubense*) (Ploetz *et al*., 2003).[24] Júnior *et al*. (2008) have analysed how climate change is likely to favourably influence the development of BS. IPCC-based forecasts of temperature and precipitation by area and month are combined with BS-favourability levels (Table 8) to generate BS-favourability scores by area and by month. Because BS has adapted to the banana, it is hardly surprising that BS-

Table 8 Climate favourability for Black Sigatoka

Favourability for Black Sigatoka	**Temperature intervals (°C)**	**Relative Humidity Intervals (%)**
Highly favourable	25-28	> 90
Favorable	25-28	80-90
Relatively favourable	20-25 or 28-35	> 80
Little favourable	20-35	70-80
Unfavourable	< 20 or > 35	< 70

Source: Jesus Júnior *et al*., 2008, Table 1, pg. *42*

---

[23] IPCC (2007:778): "The monsoonal precipitation in Mexico and Central America is projected to decrease in association with increasing precipitation over the eastern equatorial Pacific that affects Walker Circulation and local Hadley Circulation changes."

[24] Ghini *et al*. (2011) review the emerging literature modeling the influence of climate change and the distribution of tropical and plant diseases on plantations

favourability closely follows banana suitability. When climate change generates conditions less suitable to the production of bananas, these conditions are also less favourable for BS, and when banana suitability improves, the risk of BS increases.

4.1.3 Tropical cyclones and El Niño

For bananas, a weaker tropical cyclone might blow down or defoliate plants, resulting in the loss of income for that cycle, but it would leave the root system intact, allowing the next cycle to emerge. Stronger storms could potentially result in the permanent loss of capital with the destruction of root systems, structures, equipment, irrigation, drainage and transport infrastructure. The net impact of the forecast shift in tropical storm frequency and intensity, therefore, is to increase the long-term risk of tropical cyclone damage in many major banana producing areas, specifically in Central America, the Caribbean, the Philippines and mainland South-East Asia.[25] The higher risk may reduce or alter the form of investment in banana production in these areas; it could also increase the relative attractiveness of banana production in areas with little or no risk of tropical cyclones, such the Pacific coast of Colombia, Ecuador and Peru. The South Atlantic has a very low incidence of tropical storms; this increases the attractiveness of Brazil for banana production. Similarly, Angola has -and is -forecast to maintain a suitable climate for bananas and has minimal tropical cyclone risk. Angola had a banana boom in the 1960s, but exports collapsed after the onset of the Angolan civil war (1975-2002). Developing banana production in Angola, however, would require major investments in infrastructure.

4.2 Impacts within Ecuador

4.2.1 Temperature

Commercial banana production in Ecuador is concentrated along the Pacific coast and at low altitudes. The moderating influence of the lower ocean surface temperature is likely to moderate the temperature increase.

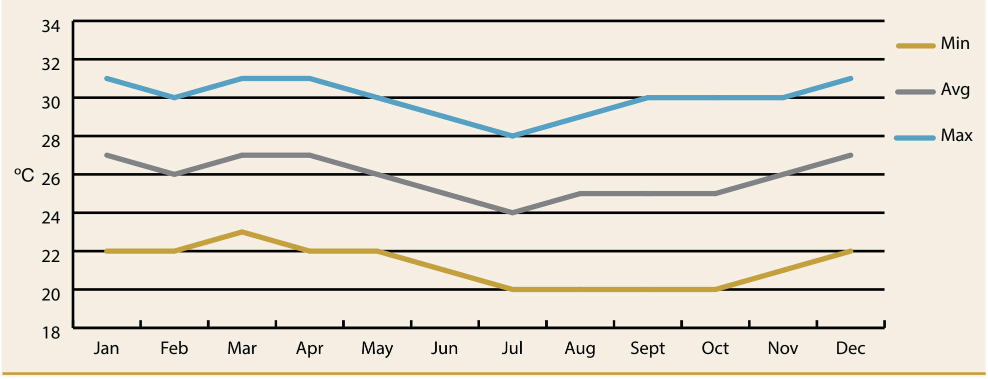
Figure 15 plots the monthly average daily mean, maximum and minimum temperatures for Guayaquil, Ecuador, which is a proxy for most commercial banana producing areas in Ecuador.[26] The stability of the equatorial climate - its minimal seasonality - is evident in the graph: the temperature is relatively constant year round. This is favourable for banana production, which also occurs year round. Will the projected increase in average temperatures shift Ecuador out of this ideal climate zone? To answer this question, modellers construct a climatic suitability score for banana production locations, using critical temperature and

---

[25] The risk of tropical cyclones is not explicitly included in the suitability measures calculated by Ramirez *et al*. (2011) and Van den Bergh *et al*. (2010); they focus appropriately on the two key determinants of suitability: temperature and rainfall.

[26] Guayaquil has an altitude of 4 m. This is lower than most banana production areas in Ecuador and, thus, it slightly overstates the temperature. For a standard atmosphere, the temperature decreases by 0.65°C for each 100 m increase in altitude

Figure 15 Monthly temperatures in Guayaquil



Source: http://www.guayaquil.climatemps.com/

rainfall levels for the crop in question. For commercial bananas, the optimum daily average temperature is between 26°C and 28°C, but plants can tolerate averages between 24°C and 31°C; above and below this range, suitability would diminish.[27] Generally, average temperatures below 16°C and above 33°C make commercial production unviable. Banana plants effectively shut down at temperatures above 34°C and suffer permanent damage above 40°C.

Similarly, permanent damage occurs below 10°C. Coastal Ecuador has an ideal climate for banana production and the magnitude of temperature increases projected for 2030 and 2050 will not seriously erode its suitability. Figure 15 only plots monthly averages of daily maximum temperatures; unusually hot and cool afternoons do occur but 90 percent of the variation in daily maximum is within approximately 2°C of the monthly average. In other words, one would expect the maximum daily temperature to be more than 2°C above the average maximum approximately 5 percent of the time. Temperatures that exceed the critical 34°C point are currently infrequent; at higher temperatures, the risk of exceeding 34°C would increase, but not so much as to seriously impair the capacity for commercial production. Higher temperatures, however, would shorten the time to maturation and result in smaller fruit than in the current climate. (See below for disease incidence and severity).

The projected temperature increase for the end of the twenty-first century of 3°C above current values will pose a serious threat to the commercial production of bananas. The average daily maximum temperature will exceed 34°C approximately half of the time in March and April and will present a 5 percent risk, even in the relatively cool months of July and August.

---

[27] These values are drawn from Robinson and Gálan Saúco (2010), which is oriented towards commercial banana production (see Chapter 4: Climatic Requirements and Problems, pp. 67-88). Ramirez et al. (2011) apply a slightly lower temperature range to allow for a wider range of banana and plantain varieties and a wider range of environments (e.g. at higher elevations). Similarly, Van den Bergh *et al*. (2010) apply an even lower range of temperatures because of their focus on varieties adapted to the sub-tropics.

4.2.2 Precipitation

Most IPCC climate models forecast that surface sea temperatures will increase more in the eastern equatorial Pacific region than in the western Pacific region. The climate, therefore, would become slightly more El Niño-like.[28] The net result would be more rainfall along the coast of Ecuador and northern Peru. The central IPCC forecast for Coastal Ecuador for 2080-2099 (relative to 1980-1999) is for an increase of about 0.5-0.7 mm/day of precipitation in the months of December, January and February and an increase of about 0.7 to 0.9 mm/day in the months of June, July and August. Coastal Ecuador currently has a rainy season from late December through mid-May; otherwise, there is almost no precipitation. Average monthly rainfall for December to February is 160 mm and for June to August, 4 mm. The end-of-century changes that are forecast would increase the current averages to 178 mm and 28 mm (using the mid-points of the forecast ranges and 30-day months).[29] Increased rainfall would potentially be more beneficial than harmful for Ecuador's banana production. If the increase comes in the form of occasional violent downpours, then harm would be probable. If the increase is distributed evenly as slightly more rain than occurs currently, it would be beneficial, since it would somewhat reduce the reliance on irrigation in the drier months.[30]

The reduction of Andean glaciers and snow fields means that less precipitation is stored as ice and snow. A reduced glacial buffer increases water discharge during the rainy season, stressing existing river and water management systems. Increased discharge in the rainy season means reduced discharge in the dry season, which poses a major threat to water supplies in the Sierra. The coastal region is not as exposed to these dry season risks, but greater discharge during the rainy season would likely require greater attention to water management, particularly in ensuring drainage and flood control.[31]

4.2.3 Disease

In Ecuador, higher temperatures potentially will make conditions slightly less favourable for BS, but this may be offset by higher rainfall and higher relative humidity. The influence of higher-than-expected rainfall on BS-favourability may increase the duration of the rainy season, resulting in more months with an average relative humidity exceeding 80 percent. Under all IPCC scenarios, Ecuador will remain at least proportionately BS-favourable.[32]

---

[28] "These background tropical Pacific changes can be called an El Niño-like mean state change (upon which individual El Niño-Southern Oscillation (ENSO) events occur)." IPCC (2007: 779).

[29] IPCC rates these forecasts as likely; that is, as having at least a 66 percent chance of being correct. The prediction for December to February is more likely than the June to August forecast, but the potential is not sufficient to merit the rating 'very likely' with a 90 percent chance of being correct.

[30] It may require, however, more fungicide use.

[31] With regard to Andean glaciers and water resources, see Chevallier *et al*. (2011), Rabatel *et al*. (2013) and Bradley *et al*. (2006). Arias-Hidalgo *et al*. (2013) focus on challenges facing the Guayas River Basin.

[32] Ghini *et al*. (2007) examine BS-favourability relating to Brazil. Given the high-resolution climate projection data, a similar study could be produced in relation to Ecuador.

The probable incidence and severity of Panama disease has not yet been analysed in conjunction with IPCC predictions. Gasparotto and Pereira (2008) argue that higher temperatures and drought stress may increase plant susceptibility to Panama disease. This is a different pattern from that of BS-favourability. In Ecuador, higher average temperatures point towards greater susceptibility, but this is partially offset by a lower risk of drought stress.

5. Summary

In sum, climate change between today and the middle of this century will unlikely present a major challenge to Ecuador's capacity to produce bananas, although climate conditions will become gradually less favourable for banana production. In the second half of the century, however, higher average temperatures could begin to damage banana plants and force major changes in production. Higher rainfall and reduced glacial buffers may increase flood risk and challenge existing water management systems. One possible adaptation would be to shift banana production to higher altitudes, but a 500 m increase in altitude would be needed to offset fully the mean IPCC-predicted increase of 3.3°C. A concern with the shifting of planting upslope is deforestation. From a climate change mitigation perspective, it will be important to reforest the former areas of banana production.[33] Another potential adaptation is the development and adoption of varieties that grow in high temperatures.[34]

In Ecuador, the increased uncertainty about ENSO suggests that small insurance-premium-like actions against extreme ENSO events will have a higher payoff in the future than they have had in the past. The loss to the banana sector from an extreme ENSO event is most likely to be the result of a severe rainfall. The risk is compounded by the reduction of glacial and snowfield buffers. Combined, this argues the case for increased attention to flood, drainage and emergency systems for a wider range of adverse rainfall outcomes.

---

[33] See Wunder (2001).

[34] See Van den Bergh, Amorim and Johnson (2013) and Pillay, Ude and Kole (2012).

Box 1 Ecuador's climate change strategy

Ecuador's development orientation is articulated under the national Good Living strategy that aims to improve the quality of social care services required to ensure the health of the population through health and environmental best practices and land management.

Measures to mitigate and adapt against climate change fall also under the Good Living strategy. The priority areas for climate action include the following:

- Mainstream mitigation and adaptation to climate change in the planning and investment of different levels and sectors of government in a coordinated and articulated manner.
- Implement climate change impact assessments and study the vulnerability and risk to productive sectors and communities, focusing on vulnerable groups and fragile ecosystems.
- Minimize the impact of climate change on the natural heritage, life cycles and supply of goods and services provided by different ecosystems.
- Include criteria for the mitigation and adaptation to climate change in the formulation and evaluation of strategic plans/projects and in the provision of infrastructure and services.
- Develop activities to increase knowledge, awareness and citizen's participation in activities related to climate change management.
- Strengthen the National Information System with geospatial and statistical documents, with emphasis on hydrometeorology and agroclimatology, for the constant monitoring of climate change, while considering risk factors and vulnerability.
- Build human capital; strengthen technical capacity and negotiation skills; and implement policies for the mitigation and adaptation to climate change.
- Promote applied research in technology while valuing ancestral knowledge and sustainable practices for the prevention, mitigation and adaptation to climate change.
- Promote the elimination of perverse incentives to reduce GHG emissions in the sectors that are dependent on fossil fuels.

Box 1 Ecuador's climate change strategy (cont'd)

- Design mechanisms and incentives for agricultural and industrial production systems, based on agro-ecological principles and the use of clean energy technologies.
- Strengthen national participation in international climate change negotiations to ensure technology transfer and consolidation of a new financial architecture.
- Strengthen the sustainable and equitable management of the global commons by influencing international negotiations and international commitment to innovative national initiatives, such as net emissions avoided, special drawing rights and the Daly-Correa tax, with geopolitical criteria and intergenerational justice.


©FAO/Aziz Elbehri

CHAPTER 4:

ASSESSMENT OF CLIMATE CHANGE IMPACT ON BANANA PRODUCTION AND SUITABILITY IN ECUADOR, AND GENERAL ASSESSMENT OF GLOBAL BANANA TRENDS UNDER CLIMATE CHANGE SCENARIOS

Germán Calberto*; Patricia Alvarez Toro*; Pablo Siles; Jessenia Arguello*;**
Charles Staver*; Ignacio Sotomayor*; Antonio Bustamante*****

* Bioversity International (CCAFS)
** International Centre for Tropical Agriculture, Nicaragua Office
*** Instituto Nacional Autonomo de Investigaciones Agropecuarios (INIAP), Ecuador

1. Introduction

The pace and extent of climate change and its environmental and social implications have become an increasing concern to the scientific community and the public and private sectors. Numerous predictions have been issued about the effects on agriculture, which could extend from the local into the global economy. Sector-based and national planning and monitoring have been proposed to address the anticipated effects of climate change. The media has highlighted the increasing incidence of pests and diseases and emergence of plant health problems in crops important to national economies. The global banana sector is not isolated from these discussions. Of the three key challenges facing the banana industry identified during the 5th International Banana Congress, held in Costa Rica on 24-27 February 2014 - (i) adaptation measures to minimize the effects of climate change; (ii) increased environmental sustainability; and (iii) meeting consumer demands on banana quality and labelling - two relate to climate change.

Climate change is projected to disrupt agricultural production, threatening food security and the incomes of millions of households in Latin America. Not only will average temperatures increase, but these will also generate more frequent and severe weather events, reducing crop yields and increasing incidence of pests and disease. Unless measures are taken to strengthen the resilience of production systems, the agricultural yields and production will become increasingly variable over the medium and long terms.

The banana is the most important agricultural commodity in Ecuador. Ecuador is also the foremost exporting country of bananas and ranks as the fifth country in terms of total world production (6-7 percent). Bananas generate nearly 4 percent of gross national product (GNP); 50 percent of agricultural GNP and 20 percent of export earnings (AEBE, 2010). Banana production and its related industries are the source of employment for more than 1 million families, approximately 17 percent of Ecuador's population, who depend in one way or another on the banana industry. Clearly, the impact of weather events on Ecuador's banana production will also have a direct impact on the country's economy. The wellbeing and food security of those households that are linked directly or indirectly to the crop will also be affected.

In its efforts to develop the response capacity of key global commodities, FAO's Trade and Markets Division has initiated a program of case studies and technical assistance. This particular study relates to Ecuador's banana industry and addresses not only the nature of climate change and the need for adaptation, but also the potential for mitigation and the lowering of the carbon footprint. The results include the implications on banana production, yields and suitability.

The study addresses the following:

i. A comprehension of the potential role of climate change and variability on Ecuador's banana production and the leaf diseases in primary banana growing areas, drawn from existing information that is based on the CGIAR's research program, Climate Change, Agriculture and Food Security (CCAFS), Instituto Nacional Autónomo de Investigaciones Agropecuarias (INIAP) and the Centre de coopération internationale en recherche agronomique pour le développement (CIRAD). The analysis will cover present and future projections, using the global circulation models for the years 2030, 2050, and 2075.

ii. An estimation of the indicators and identification of types of climate variability in terms of moderate variability and extreme events (rainfall, drought, heat waves and cold snaps) for the main banana and plantain growing areas of Ecuador. The analysis will apply Worldclim and historical weather data from three weather stations in banana zones and their related upper watersheds within Ecuador that are the source of irrigation water.

iii. The documentation relating to focal group discussions with banana growers and technicians in select key production areas relating to the effects of moderate and extreme weather events on banana productivity and the identification of management strategies; prevention of additional costs; and the recovery from these effects.

iv. A review of the disruptive effects of moderate and extreme climate events in Ecuador on the volume of exported bananas, using historical data.

2. Projected impact of climate change and weather variability on the levels of productivity and disease

To address the impact of climate change and weather variability on the levels of Ecuador's banana production and disease, an identification of the production areas was made. These were classified into agroclimatic zones, based on banana-specific parametres. Average climate changes were projected for the zones and for six representative sites. These projections provided the basis to study the changes in the areas relating to suitability, climate change links to disease severity and upper watershed effects.

2.1 Export banana production areas of Ecuador

Banana growing areas cover nearly 210 000 hectares and are concentrated principally in the coastal provinces of Guayas, Los Ríos and El Oro. These provinces represent approximately 91 percent of the production area and 89 percent of the growers (AEBE, 2014) (Figure 16). Additional production is found in the Sierra in the lower altitudes of the provinces of Cañar (3.8 percent of national banana production), Bolívar (1.8 percent), Pichincha, Santo Domingo de los Tsachilas (1.4 percent) and Loja (0.8 percent). Much smaller areas are located in other provinces. Yields are influenced by management practices and inputs, the size of the farm and production characteristics, such as soils, and climatic factors.

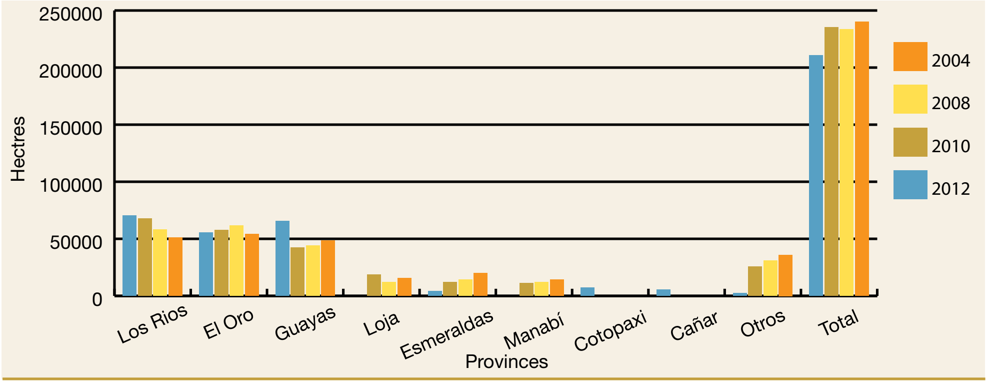
To classify the areas that meet a range of suitability criteria for banana production throughout Ecuador, a spatial modeling procedure was developed and implemented in ArcGIS (ESRI Inc.), using the ESRI Model Builder. Environmental and other global geospatial datasets that were used for the global classification analysis include:

- Actual Mean Monthly Temperature (Spatial resolution: – 5 kilometer (km) – 2.5 arc-min); and
- Actual Mean Monthly Precipitation (Spatial resolution: – 5 kilometer (km) – 2.5 arc-min)

These data sets can be found in the portal, WorldClim (Hijmans *et al*., 2005). Areas not suitable for banana production were defined as areas with three or more months, with temperatures below 13ºC or with one or more months with temperature higher than 35ºC (see Table 9 for key temperature parametres for banana growth). All areas that are not likely to be suitable for banana, due to the low or high temperature were excluded from the analysis. The global suitable areas were classified into Tropical and Subtropical banana production areas. For Ecuador, only tropical production areas were discovered, which were classified into categories of temperature, precipitation and dry months (Table 10). Actual banana growing areas for Ecuador were obtained from http://www.crop-mapper.org/banana/.

This overlay of current banana production areas on the agroclimatic map (Figure 17) shows that banana production is located in four principal zones with temperatures greater than 24°C and dry seasons that last longer than 3 months, although annual rainfall varies from <900mm to >2500mm. The monthly distribution of precipitation follows the same pattern for the banana growing areas, with highly seasonal rainfall. Five to six dry months with little rainfall, from June to November, are followed by six to seven wet months. A period of low temperatures occurs in July and August, while temperatures are several degrees higher the remaining months of the year. Other production is found to the North, where the dry season is shorter, and to the East which has slightly lower temperatures. Six points were selected to represent the distribution of the banana growing areas in the important agroclimatic zones (Figure 17, Table 11). These are also sites with weather stations which are proposed to facilitate analysis, using historical weather records.

Figure 16 Banana production areas of Ecuador, by province



Source: AEBE, 2014

Table 9 Key temperature parametres for banana growth

Temperature (°C)	Effect of temperature on banana growth
47	Thermal danger point, leaves die
38	Growth stops
34	Physiological heat stress starts
27	Optimum mean temperature for productivity
13	Minimum mean temperature for growth; field chilling
6	Leaf chlorophyll destruction
0	Frost damage, leaves die

Source: AEBE, 2014

Table 10 Agroclimatic zones

	<900 mm (1)			900- 1500mm (2)			1500-2500 mm (3)			>2500 mm (4)		
>3 dry mths	13-18°C (1)	18-24 °C (2)	>24°C (3)	13-18°C (1)	18-24°C (2)	>24°C (3)	13-18°C (1)	18-24°C (2)	>24°C (3)	13-18°C (1)	18-24°C (2)	>24°C (3)
(1)	111	121	131	211	221	231	311	321	331	411	421	431

	<900 mm (1)			900- 1500mm (2)			1500-2500 mm (3)			>2500 mm (4)		
>3 dry mths	13-18°C (1)	18-24 °C (2)	>24°C (3)	13-8°C (1)	18-24°C (2)	>24°C (3)	13-18°C (1)	18-24°C (2)	>24°C (3)	13-18°C (1)	18-24°C (2)	>24°C (3)
(2)	112	122	132	212	222	232	312	322	332	412	422	432

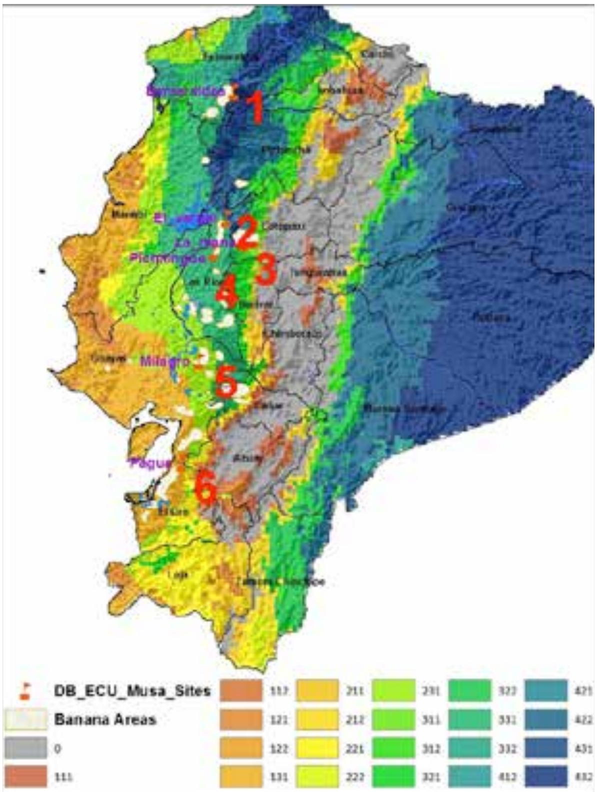
Source: AEBE, 2014

Table 11 Six representative points for the major banana production areas of Ecuador

Location	Agro-climatic zone	Description
1. Esmeraldas	432	>2500 mm, >24 ºC, <3 dry months
2. El Vergel (Los Ríos)	431	>2500 mm, >24 ºC, >3 dry months
3. La Mana (Cotopaxi)	321	1500 – 2500 mm, 18-24 ºC, >3 dry months
4. Pichiingue (los Ríos)	231	1500 – 2500 mm, >24 ºC, >3 dry months
5. Milagro (Guayas)	131	900 – 1500 mm, >24 ºC, >3 dry months
6. Pagua (E Oro)	131	<900 mm, >24 ºC, >3 dry months

Source: Authors' elaboration, based on temperature and precipitation data from WorldClim (Hijmans *et al.*, 2005)

Figure 17 Agroclimatic zones, major banana growing areas and selection of six points to represent the different climatic conditions



Source: Authors' elaboration, based on temperature and precipitation data from WorldClim (Hijmans *et al*., 2005)

2.2 Projected changes in climate in principal export banana production areas to 2070

Based on this information, the effects of changes in average temperature and annual rainfall were projected for 2030, 2050 and 2070, using data from the CCAFS database portal (Ramírez and Jarvis, 2008) with the same resolution of 5 kilometres (km). Projections assume scenario A2[35] and the average of 20 general circulation models.

Table 12 shows the likely effect of climate change on the extent of the agroclimatic zones. In general, conditions for banana growth across Ecuador

---

[35] A2 scenario assumes a heterogeneous world with slow convergence, continued population growth and slow per capita economic growth.

will improve, as indicated by the decline in area not suitable for banana (row 0 in Table 12). Certain zones will increase in area, while other zones will decline. For the four climates of primary importance relating to current banana production, the driest zone will remain approximately the same in land area, while the production areas from 900 mm to more than 2 500 mm annual rainfall will increase by over 1 600 km^2.

Using the six points to specifically examine climate change projections permits a more detailed perspective. These graphs (Figure 18) illustrate the current monthly temperature and rainfall, as well as those for 2030, 2050 and 2070. The highly seasonal rainfall distribution, with over five dry months, will continue

Table 12 Current and future agroclimatic zones (in km^2)*

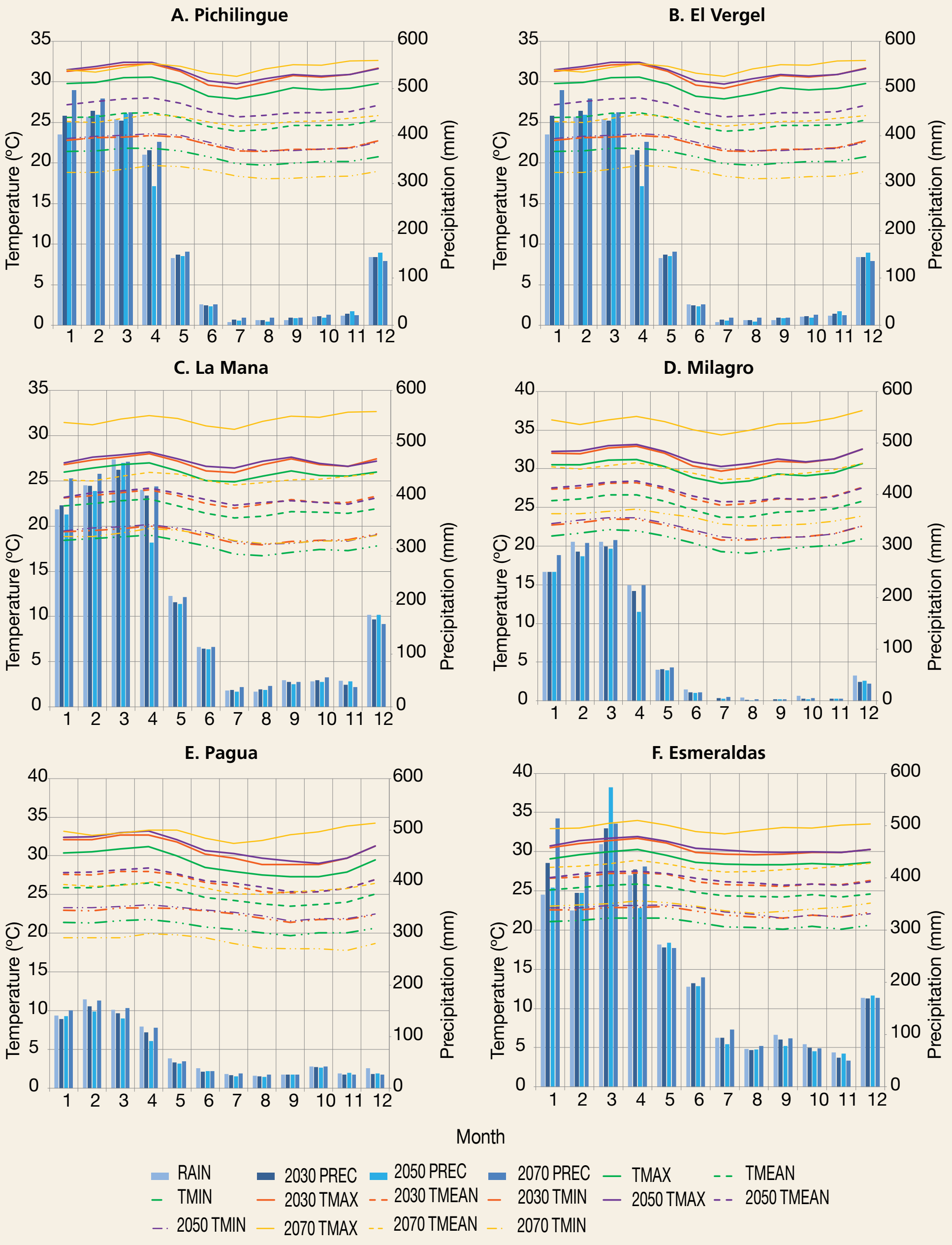
	Area (km^2)				
Agro-zone-ID	**Actual**	**2030**	**2050**	**2070**	
0	4 122.5	3 340	2 805	2 352.5	-
111	712.5	935	1 000	827.5	
112	25	42.5	27.5	40	
121	1 382.5	487.5	375	417.5	-
122	2.5	0	5	12.5	+
131	2 207.5	2 860	2 820	2 725	
211	475	495	520	582.5	+
212	777.5	825	880	1 045	+
221	1 187.5	777.5	680	627.5	-
222	315	437.5	535	555	+
231	1 712.5	2 222.5	2 487.5	2 607.5	+
232	0	25	82.5	182.5	+
311	47.5	30	22.5	12.5	-
312	855	517.5	347.5	262.5	-
321	530	300	227.5	167.5	-
322	1 187.5	1 307.5	1 180	1 195	
331	1 770	2 145	2 262.5	2 357.5	+
332	530	510	657.5	692.5	+
412	152.5	47.5	12.5	7.5	-
421	92.5	20	15	35	
422	3 485	2405	1990	1 365	-
431	210	310	362.5	405	+
432	8 230	9 825	1 057.0	11 390	+

Source: Authors' calculations

* Important banana climates are in bold and italics

** The last column identifies, with + (increase) or – (decrease), the change over the 56 year period

Figure 18 Average monthly precipitation and temperature for six representative points of the Ecuadorian export banana and plantain sector*



*: Using average values for 20 GCMs under scenario A2. A: Pichilinge (Los Ríos), B: El Vergel (Los Rios), C: La Mana (Cotopaxi), D: Milagro (Guayas), E: Pagua (El Oro), F: Esmeraldas (Esmeraldas)

unchanged - with a small annual increase of 200 mm in total. The average temperature will increase over the next 50 years by over 3°C from 25°C to 28°C. This is a general effect across all six sites. Even with these changes, the average growing conditions for banana will remain favourable in the major banana growing areas of Ecuador. An average temperature of 28°C is still within the optimum range, while irrigation and drainage will continue to be an important element of crop management.

The analysis, based on growing conditions for banana, provides an overview of the effects of average climate change. Diverse tools have been used to convert the general requirements for growth into more quantified effects. For example, Climate Envelope Models, such as Maxent, Bioclim and Ecocrop, have been applied for many different crops and natural ecosystems, and Ecocrop has been used in relation to the banana (Van den Bergh *et al*., 2012). Models, such as Ecocrop, use annual data for temperature and rainfall, which limit their applicability for crops, which have a 12- month cycle and which may use irrigation.

To have a quantitative index of the effects of changing temperature and water availability on banana growth, a calculation was developed, using monthly temperature and rainfall based on leaf emission rate. Leaf emission rate is a key variable in banana productivity, since the rate of leaf emission is closely correlated to the length of the vegetative cycle and the duration from one bunch to the next for each banana mat. Leaf emission rate is highly influenced by temperature and available water. Three calculations were carried out: (i) effect of temperature alone, measured by growing degree days (GDD); (ii) thermal development units (TDU) in which GDD are combined with available soil water; and (iii) water deficit based on a water balance, using natural rainfall and optimum crop needs. All three calculations were carried out for current conditions and compared with projections for 2030, 2050 and 2070.

2.2.1. Estimation of banana GDD and TDU

GDD were used as a measure of temperature requirements for banana plants and could be used to estimate growth and development. Banana plants are generally considered day-neutral plants because floral induction is not highly dependent on photoperiod. (Some effect has been shown by Fortescue *et al*., (2011), but the effect has been left out for this analysis.) The anthesis or flower emergence thus occurs at any time of the year, and the emergence of the bunch may be influenced seasonally by only environmental and edaphic factors. As the photoperiod does not influence bunch initiation, the development of the plant can be best described by growing-degree-days (GDD, with units of °C days).

The basic concept of GDD is that plant development will occur when temperatures exceed a base temperature and decrease when a maximum temperature is exceeded. For the estimation of GDD, the average temperature of the month was used. The base temperature is then subtracted from the monthly average temperature to give a daily GDD. If the daily GDD calculates to a negative number, it is made equal to zero. Monthly GDD was calculated multiplying the number of days of the month and then added up (accumulated) over the year:

$$GDD = \text{Days per month (Average Monthly Temperature - Base Temperature} = 13^{\circ}C)$$

If answer is negative, assume 0; if the mean monthly temperature exceeds 35°C, then the GDD were 0 due to high temperatures (Thomas *et al*., 1998; Turner and Lahav, 1983).

In addition, TDU for banana were estimated, due to the fact that other factors than temperature are influencing bunch initiation in bananas. In several studies, there was variation in the GDD necessary for bunch initiation for the different locations, soils and planting material. The relationship between TDU and GDD for a time period is:

$$TDU=GDD * Pf * Wf\ (^{\circ}C\ d)$$

Where ***Pf*** is a scalar (0.0 to 1.0) for photoperiod and ***Wf*** is a scalar (0.0 to 1.0) for soil water balance. ***Pf*** was not taken into account in this study. The soil water balance (***Wf***) was estimated monthly, from the ratio of rainfall: potential evaporation (Rain: PET) taking ***Wf*** as 1.0 if the ratio fell between 1.0 and 1.1. If Rain: PET was above 1.1 then ***Wf*** = 1 + 0.2(1– Rain: PET), allowing for a negative effect for excess of water (Fortescue *et al*., 2011).

2.2.2 Estimation of water deficit

The irrigation water need or water deficit for banana was estimated as the difference between the crop water need as measured by actual evapotranspiration(***AET***) and that part of the rainfall which can be used by the crop (the effective rainfall –***Erain***-). It was determined on a monthly basis and then summarized for the year.

$$\text{Water Deficit (Irrigation Water Need)} = AET - ERain$$

2.2.3 Monthly potential evapotranspiration

Potential evapotranspiration (PET) was estimated on a global scale to calculate the TDU and the banana water deficit. PET is a measure of the ability of the atmosphere to remove water through evapotranspiration (ET) processes. PET has been defined as ET of a reference crop in optimal conditions, having the following characteristics: well watered grass with an assumed height of 12 cm, a fixed surface resistance of 70 seconds per metre (s/m) and an albedo of 0.23 (Allen *et al*., 1998). Other methods of calculating PET exist, however, and the Hargreaves model was chosen to model PET globally for this study (Hargreaves and Allen, 2003). This method performed almost as well as the FAO Penman-Monteith, but required less parameterization (Hargreaves and Allen, 2003; Trajkovic, 2007), allowing a finer resolution (at 10 km resolution). The Hargreaves model uses mean monthly temperature (Tmean) and global solar radiation (Rs) at the surface to calculate PET, as shown below:

$$PET = 0.0135 * (Tmean + 17.8) * Rs * \text{days per month}$$

The Rs is expressed in units of water evaporation (mm = 2.45 W m^{-2})

2.2.4 Actual evapotranspiration

Actual evapotranspiration (AET) is the quantity of water that is removed from the soil due to evaporation and transpiration processes (Allen *et al*., 1998). AET is dependent on the vegetation characteristics, quantity of water available in the soil and soil hydrological properties (mainly soil water retention curves):

$$AET = Ksoil * Kc * PET \text{ (mm/month)}$$

where: **Ksoil** = reduction factor dependent on volumetric soil moisture content (0-1), Kc = banana crop coefficient dependent on the development of the crop (0.3-1.3). The crop coefficient (**Kc**) is used to estimate the crop water use form reference PET for different crops or vegetation types. **Kc** values for bananas were taken from the literature (Allen *et al*., 1998; Freitas *et al*., 2008; Silva and Bezerra, 2009).

2.2.5 Effective rainfall

Rain interception is the process by which precipitation is intercepted by the vegetation canopy (canopy interception losses), where it is subject to evaporation. Interception has an important role in the water budget, as it reduces the amount of precipitation available for soil moisture. The losses due to interception depend on vegetation type, vegetation cover and the intensity, duration and frequency of precipitation (Siles *et al*., 2010). The vegetation interception is a purely mechanic function of the storage space of vegetation structure. The effective rainfall (ERain) in this study was estimated using the FAO/AGLW equation. FAO/AGLW developed an empirical formula, based on analyses undertaken for different climatic data to determine the dependable effective rainfall (FAO, 2001; FAO, 1992):

For each month, ERain is calculated as:

$$ERain = 0.6 * Rain_{tot} - 10 \quad \text{for } Rain_{tot} <= 70 \text{ mm}$$
$$ERain = 0.8 * Rain_{tot} - 25 \quad \text{for } Rain_{tot} > 70 \text{ mm}$$

Where: ***ERain*** is the effective rainfall and ***Rain***$_{tot}$ is the total month rainfall.

Table 13 Banana crop coefficients (Kc) found in the literature for different cultivars

Banana cultivar	**Kc at different stages**			**Reference**
	Initial	**Medium**	**Final**	
Prata Ana	0.8 (0-100 d)	1.0 (100-160 d)		Silva and Bezerra 2009
Pacovan	0.9 (0-100 d)	1.0 (100-160 d)		Silva and Bezerra 2009
Cavendish	0.4	1.2	1.1 Final 1st	Allen 2006
Pacovan	0.6	1.1-1.3		Freitas *et al.* 2008
Cavendish	0.5	0.8	1.1-1.4	Freitas ***et al.*** 2008
Pacovan	0.65	0.9-0.95	0.8-0.7	Bassoi ***et al.*** 2004

These different measures of the effects of average climate change are carried out using crop characteristics for Cavendish, which has a low temperature threshold of 13°C and requires 108 GDD for the emission of a leaf. Calculations for current conditions and monthly temperature and precipitation projections for 2030, 2050 and 2070 were completed for each of the six points selected earlier, which represent the growing conditions for export banana and plantain on the Ecuadorian coast.

The calculations for GDD (Table 14) show that total leaf emission for a 12-month period will increase by 4-6 leaves by 2030, with little increase from 2030 to 2050, even though temperatures will continue to rise in that period. From 2050 to 2070, total annual leaf emission will decline for some sites while increasing for others. If irrigation is optimum, these emission totals can be expected. Using TDU, the effects of water limitation under rainfed production are taken into account. Totals are only about one half the total leaf emission, based on GDD, and there is relatively little change from the present day to 2070. Water will continue to limit the total leaf emission, rather than temperature, under rainfed conditions. Although temperature and rainfall are projected to increase, the increase in water is largely during the rainy months and, therefore, does not compensate the increase in temperature. Total annual leaf emission is projected to be stable.

From the present through to 2070, the increase in average temperature will result in an increase in crop water demand to meet PET. The amount of water to

Table 14 Total annual leaf emission, based on temperature (GDD) and temperature and water (TDU)

Region	Baseline	2030	2050	2070
	Total leaf emission based on temperature (GDD)			
El vergel	38	44	44	41
Esmeraldas	40	45	46	51
La Mana	30	34	34	42
Milagro	41	47	47	57
Pagua	40	46	47	44
Pichilingue	41	46	47	42
	Total annual leaf emission based on temperature and water (TDU)			
El vergel	20	22	23	21
Esmeraldas	28	30	30	34
La Mana	16	18	19	23
Milagro	16	18	18	21
Pagua	21	22	22	21
Pichilingue	19	22	22	18

Source: Authors'calculations, based on baseline and projections from CCAFS database portal (Ramírez and Jarvis, 2008).

be applied as irrigation to meet plant needs will increase by 12-15 percent over the period (Table 15). This will be the result of greater irrigation demand during the dry season.

2.3 Projections for effect of climate change on the Black Sigatoka and the banana weevil

In addition to the effects on leaf emission and water demand, average climate change may also affect the conditions for disease incidence and severity. The most important leaf disease, *Mycosphaerella fijiensis* -or BS - and an indicator insect pest, *cosmopolites sordidus* - or stem weevil - were used as indicators of the projected effect of climate change on banana pest management.

2.3.1 Black Sigatoka

To project the effect of changes in average climate on BS, daily weather data are needed. The simulator program, MarkSim™, which works at a scale of 30 arc-seconds, calculates from the WorldClim database for its simulated daily rainfall patterns (Hijmans *et al*., 2005). For each of the proposed years, 2030, 2050 and 2070, MarkSim™ was run ten times to generate daily rainfall patterns. These were then averaged to obtain a single daily rainfall pattern for the location. The calculation was done for the Pichilingue site, which has the most complete weather station data. The projected distributions were compared with the daily distribution from the

Table 15 Water demand and irrigation needs for banana in six sites in Ecuador through 2070

Region	**Baseline**	**2030**	**2050**	**2070**
		Total banana water demand (mm/year)		
El vergel	1 724	1 808	1 827	1 850
Esmeraldas	1 686	1 771	1 804	1 949
La Mana	1 479	1 512	1 540	1 699
Milagro	1 825	1 883	1 915	2 084
Pagua	1 730	1 771	1 796	1 808
Pichilingue	1 848	1 918	1 929	1 936
		Total water deficit (irrigation needs) (mm/year)		
El vergel	744	820	832	839
Esmeraldas	495	554	591	638
La Mana	591	619	633	723
Milagro	1 147	1 206	1 262	1 345
Pagua	1 267	1 359	1 408	1 353
Pichilingue	1 001	1 034	1 035	1 050

Source Authors' calculations, based on baseline and projections from CCAFS database portal (Ramírez and Jarvis, 2008).

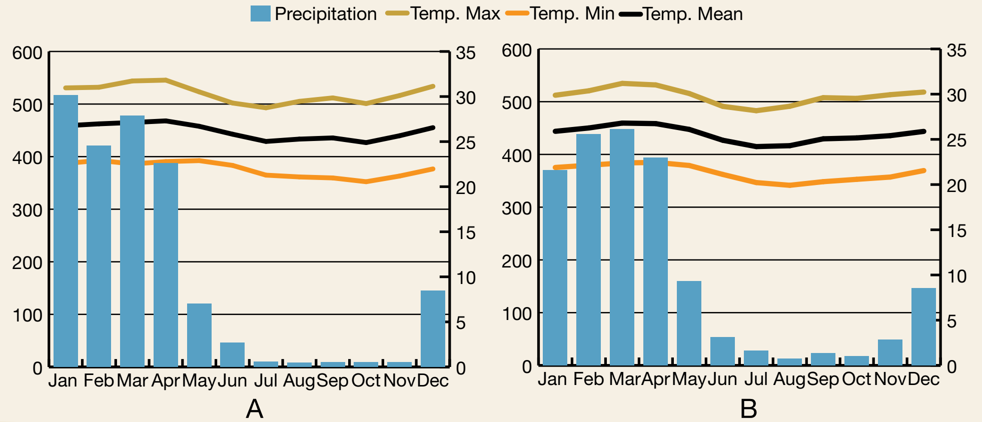
weather station (Figure 19). These daily patterns were then used in two calculations for BS - velocity of evolution and state of evolution. In the first case, the calculation is based on the relation on the speed of growth of the germination tube of conidia and ascospores linked to temperature. In the second case, disease development rate is calculated, based on the link with rainfall and humidity two weeks after.

The velocity of evolution (SDR) of BS is linked to temperature. The minimum temperature for the germination of BS, or *Mycosphaerella fijiensis*, is 12oC, the optimal is 27oC and the maximum is 36oC (Porras and Pérez, 1997; Pérez *et al*., 2006). In general, the germination of conidia is optimal between 25 and 30oC, following a quadratic response with an estimation of 26.5oC as an optimal temperature for germination. Furthermore, almost 100 percent germination is presented after 24 hours (Jacome, Schuh and Stevenson, 1991; Jacome and Schuh, 1992). For ascospore germination, an optimal temperature of 25oC was estimated (Jacome, Schuh and Stevenson, 1991; Jacome and Schuh, 1992). In relation to relative humidity, ascospore and conidia respond differently. Ascospores germinate only with a higher relative humidity than 98 percent, while conidia germinates with a wider range of humidity (88-100 percent) (Jacome, Schuh and Stevenson, 1991). The impact of the changes in temperature due to climate change on BS was estimated by the weekly cumulative sum development rates of evolution, based on the development of the germination tube (Porras and Pérez, 1997). The daily sum of development rates of evolution of BS was calculated with a simple regression, based on maximum and minimum daily temperature, developed by Porras and Pérez (1997), with the following equation:

$$SDR = 7.18 * Tmax + 79.16 * Tmin$$

Valid for a range of temperatures between 10°C and 35°C.

Figure 19 Projected distributions compared with daily distribution from Pichilingue's weather station*



*: A: MarkSim™ produced distribution, B: Pichilinge weather station

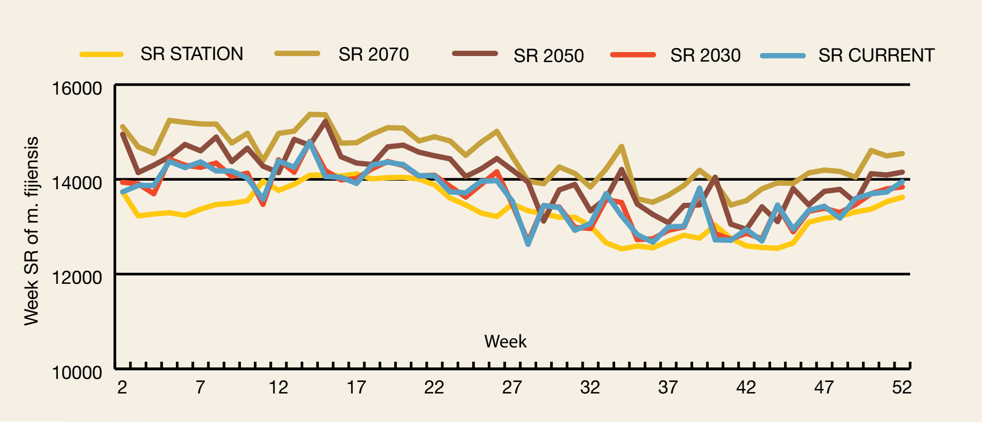
Since temperatures are projected to increase from current levels through 2070, this could result in increased growth rates for the germination tube of spores of BS and more rapid disease development. As shown in Figure 20, little increase is projected for 2030 over current rates but, by 2050 and 2070, the velocity of evolution is projected to increase.

A second approach to projecting the effect of average climate change is based on the state of evolution or advance of the disease. In general, leaf infection by BS ascospores is not observed in the absence of leaf wetness. Infection by BS conidia occurs at leaf wetness between 0 to 18 hours. Leaf lesions are presented 14 days after inoculation of plants subjected to 18 hours of leaf wetness (Jacome and Schuh, 1992). In general, the development of BS in the field could be monitored by the evolution state of BS in leaf four (EE4H) or leaf five (EE5H). Weekly changes of the state of evolution can then be used to predict the need for fungicide applications. Taking into account the delay of the disease in 14 days, Pérez *et al*. (2000) developed a model to predict the evolution state of leaf four (EE4H), based on the accumulated rainfall for 14 days five weeks before the date of predictions and the average potential evapotranspiration two weeks before the date of prediction (Pérez *et al*., 2000). The following equation was used:

$$EE4H= 1812 + 6.24 * Rainfall14_{5W} - 198.2 * (ETo_{2W}/0.8)$$

Where EE4H is the actual estate of evolution of the disease in leaf four, rainfall is the cumulative 14 days rainfall five weeks before and the ETo is the weekly average ETo two weeks before. The coefficient 0.8 was used due to the fact that the original equation used the evaporation estimated by the Piche evaporimetre which overestimated the evaporation.

Figure 20 Sums of velocity of BS evolution, based on temperature



Source: Authors' elaboration, using downscaled weather data from MarkSim weather generator

This second approach to projecting the response of BS to average climate change (Figure 21) indicates that there probably will be little change in the dynamic of BS seasonally. Since the rainfall distribution is not projected to change and this second calculation is based on wetness parametres, the disease will continue to be highly problematic during the rainy season and much less aggressive from around week 24 in the year.

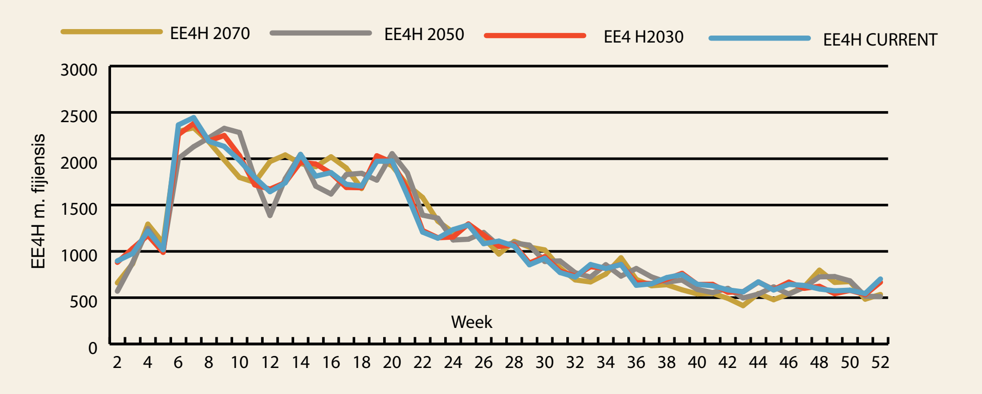
Bringing together three sources of information on BS epidemiology and management, the following implications tentatively can be proposed. The period of year when BS is the most difficult to manage will remain the same - primarily during the rainy season. The disease may become more aggressive as the velocity of growth of the germination tube of the spores is projected to increase due to a temperature response. This will only occur, however, in the presence of leaf wetness. A final factor can also be proposed in terms of management. The frequency of fungicide spraying is linked to the protection of each new emerging leaf. The leaf, when it first emerges, is an excellent trap for BS spores which later lead to infection under appropriate conditions. If leaf emission increases as has been projected, then more frequent fungicide applications may result to protect the new leaves.

2.3.2 Banana weevil

Phenology models for insects, based on temperature, are important analytical tools for predicting, evaluating and understanding the dynamics of populations in ecosystems under a variety of environmental conditions. These tools recently have been used for phytosanitary risk assessment additionally. They complement conventional research because they are a less costly option and require lower demand of time and space.

There is scant research on climate change impact on the insect pests of banana and plantain. *C. sordidus* is a key insect-pest that constrains banana and plantain production. It is very sensitive to temperature change and it could

Figure 21 State of BS evolution, based on precipitation and evapo-transpiration for Pichilingue



Source: Authors' own elaboration, using downscaled weather data from MarkSim weather generator be considered as a latent risk under climate change effects (Tonnang *et al*., 2013).

In order to estimate the effect of temperature projections on the phenology of the stem weevil, the Insect Life Cycle Modeling software (ILCYM - version 3.0) was used. ILCYM was developed by the International Potato Center and facilitates the development of pest insect phenology models and provides analytical tools for studying pest population ecology. Based on literature reviews about the development of the banana weevil under different temperature conditions and through the use of statistical tools, the necessary input data to run ILCYM was generated. ILCYM was used to simulate the phenology of *C. sordidus* and to predict the establishment risk and potential pest activity, according to temperature records. Linked with geographic information systems and atmospheric temperature models, three spatially referenced pest risk indices, displaying the risk of establishment, numbers of generations *per annum*, and an activity index were computed spatially and used to predict future changes in pest distribution and infestation due to global warming.

The simulation is based on maximum and minimum temperatures as inputs. For simulations, the set of global climate layers (grids) with a spatial resolution of 10 arc minutes (available at http://www.worldclim.org) and described in Hijmans *et al*. (2005) were used. For predicting response to climate change, similar maps - using the same resolution - were generated for climate change scenarios (using an atmospheric general circulation model). These are downloadable from the CCAFS general circulation model data portal (http://www.ccafs-climate.org/data/).

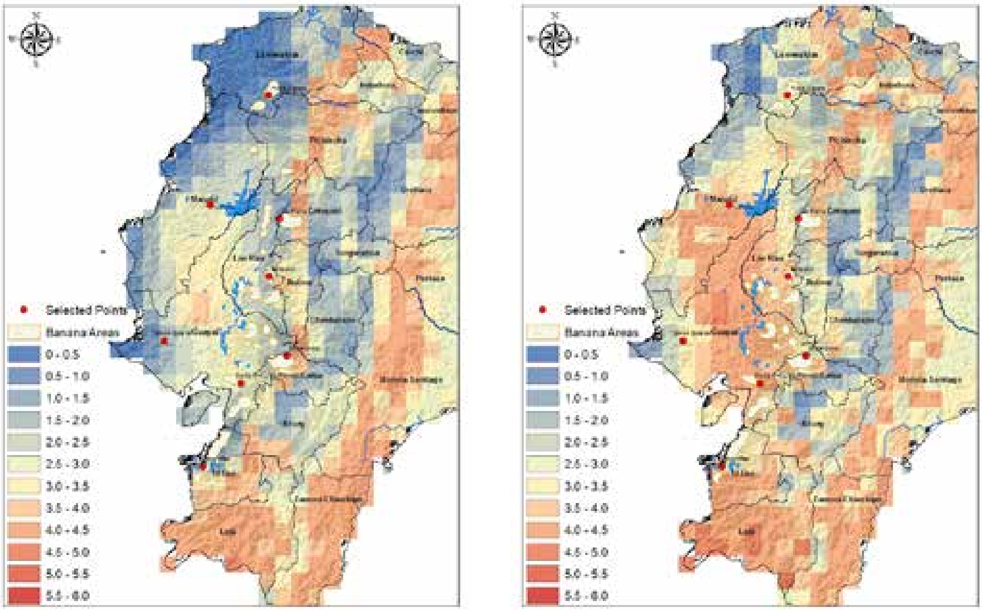
In Figure 22, the risk mapping about generation index for *C. sordidus* is presented. Our results show an increase in the generation index, suggesting a shorter biological cycle of the stem weevil, estimating a higher mean number of generations that may be produced within a year. From Figure 22, it can be noticed that the areas, where banana is currently grown, display the highest number of generations *per annum* because they provide better conditions for the development of *C. sordidus* in terms of temperature. Furthermore, new areas in the mountain region appear to be more likely to present optimal conditions for the stem weevil.

The activity index (Figure 23), which is explicitly related to the finite rate of population increase considers the entire life history of the pest. As an example, an index value of 4 would illustrate a potential population increase by a factor of 10 000 within one year. Figure 23 indicates an increase of *C. sordidus*' population in areas where temperature could become optimum for its development. This increase in population only represents the potential growth under a specific temperature regime; all other population-limiting factors, including food availability, are neglected.

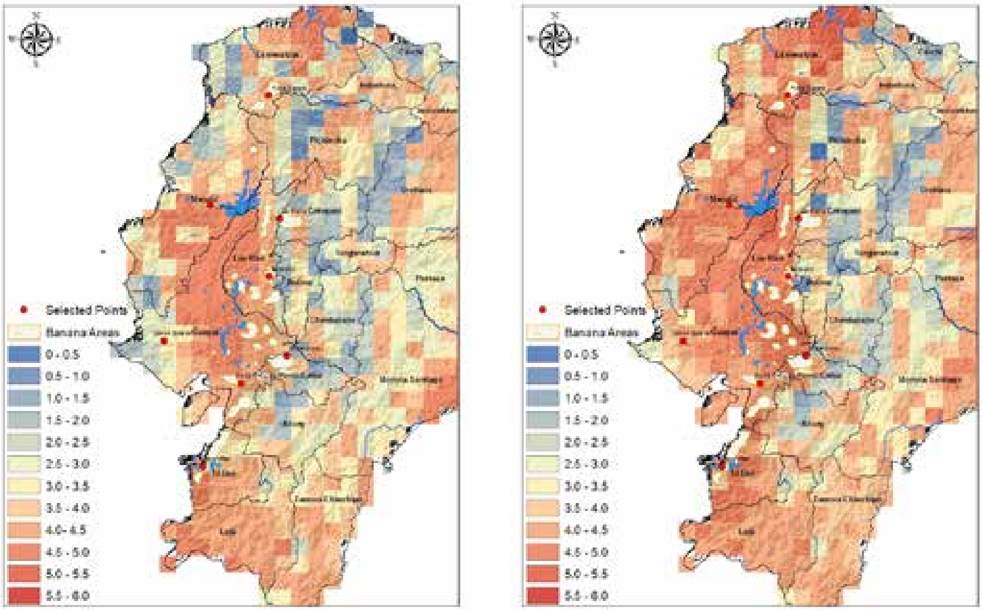
The activity index identifies areas in which *C. sordidus* may survive and become permanently established. The index is 1 when a certain proportion of all immature life stages of the pest survive throughout the year. Otherwise, the number of days in which a single stage would not survive are counted and divided by 365 (Tonnang *et al*., 2013).

Comparing current conditions with the projections for the establishment index, we found arease in suitable areas where the insect could establish due to the

Figure 22 Generation index for current conditions and projections for the years 2030, 2050 and 2070 for *C. Sordidus*



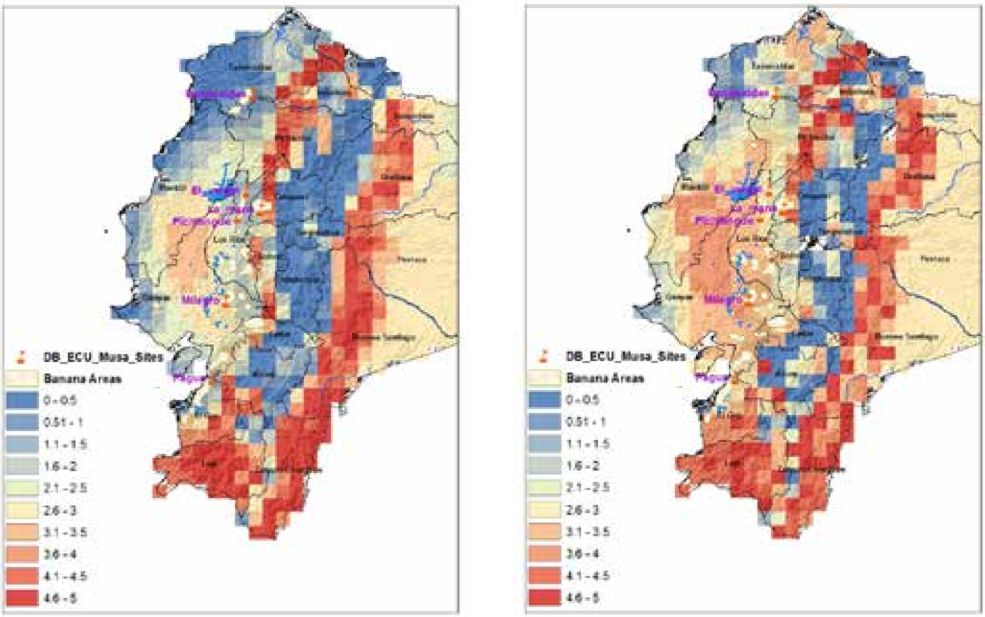
Current 2030



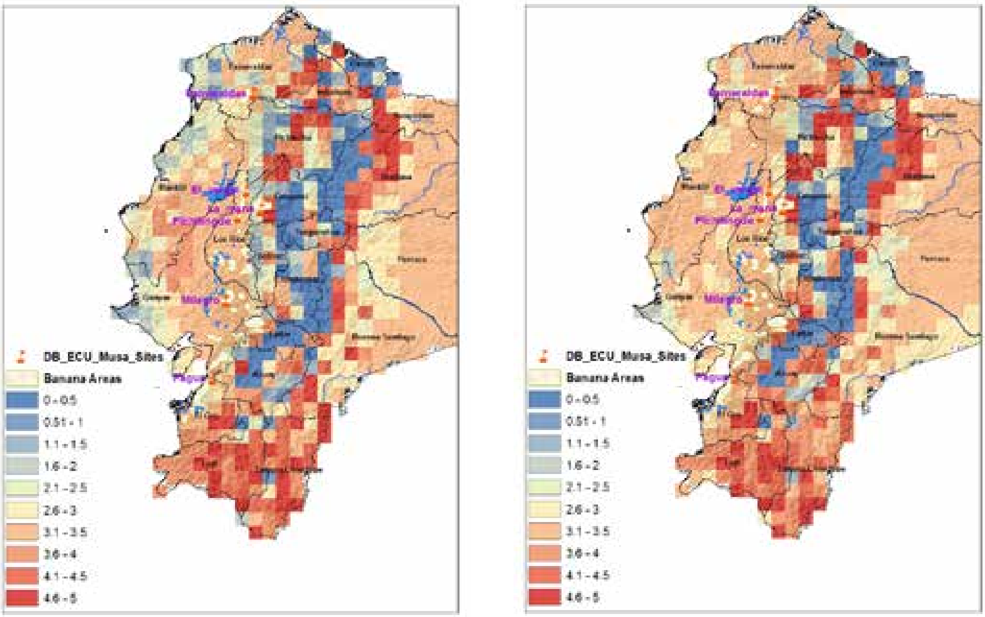
2050 2070

Source: Author's calculations

Figure 23 Activity index for current conditions and projections for the years 2030, 2050 and 2070 for *C. Sordidus*



Current 2030



2050 2070

Source: Author's calculations

projected rise in temperature (see Figure 18). In Figure 24, an increase in the risk of establishment towards highlands in the Andean region can be noted, as well as a decline in suitable areas in the coast and Amazon region, caused by high temperatures that limit conditions for the permanent establishment of the insect.

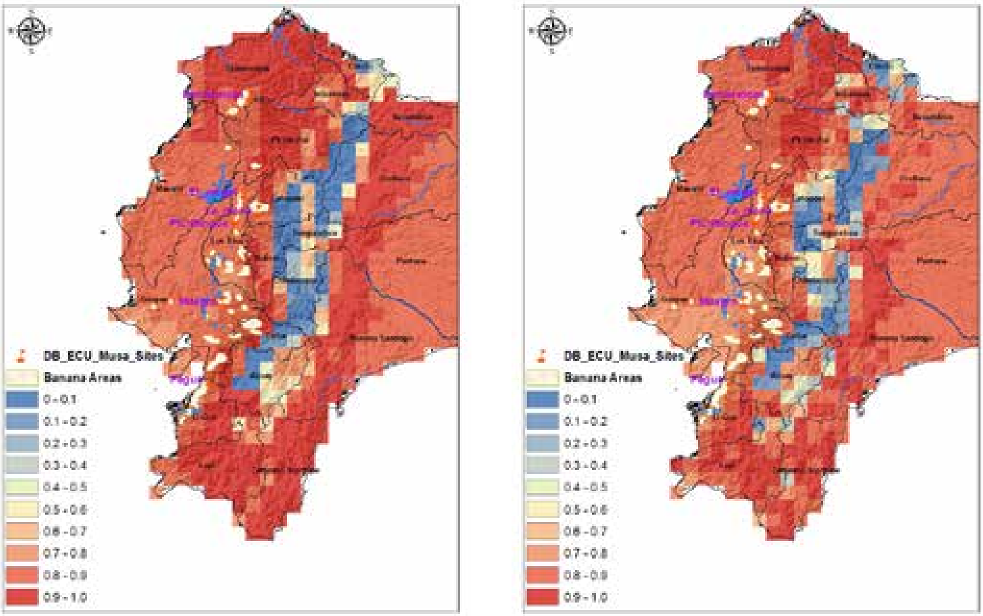
2.4 Recent history of extreme and moderate weather variability in export banana production areas and implications for the future

The 210 000 hectares of banana planted in Ecuador for export is a testimony to the suitability of the growing conditions for this crop. On average, banana prospers under the growing conditions of coastal Ecuador and is highly competitive on the world market. Average conditions, however, do not occur every year. In fact, behind the average temperature and rainfall, which is highly suitable for banana, are year after year, month after month and day after day variabilities, sometimes minor, but at other moments even catastrophic. Conde *et al*. (2006) highlighted variability in their analysis of the production of coffee in Mexico and maize in Argentina. The general climate models used to project climate change do not yet generate information about variability. With projected increases in ocean temperatures, weather may become more variable, but such projections are not yet available. For the purpose of this study, an examination is made of the historical variability under the supposition that weather will remain at least as variable in the future as it has been in the past. This variability and the uncertainty associated with it present a more immediate challenge to banana growers than the projected changes in average climate for 2030, 2050 and 2070.

The data used below to analyse weather variability were sourced from time series at the Climate Research Unit of the University of East Anglia in the United Kingdom (CRU). This database, with month-by-month records for the past century, is based on a high-resolution grid (0.5 x 0.5 degrees). Data are interpolated from weather registries from over 4 000 weather stations across the globe. This database covers standard variables such as precipitation, daily average temperature and maximum monthly temperature, as well as other variables such as cloud cover, daily temperature range and frequency of days with frost and with rain (Harris *et al*., 2013).

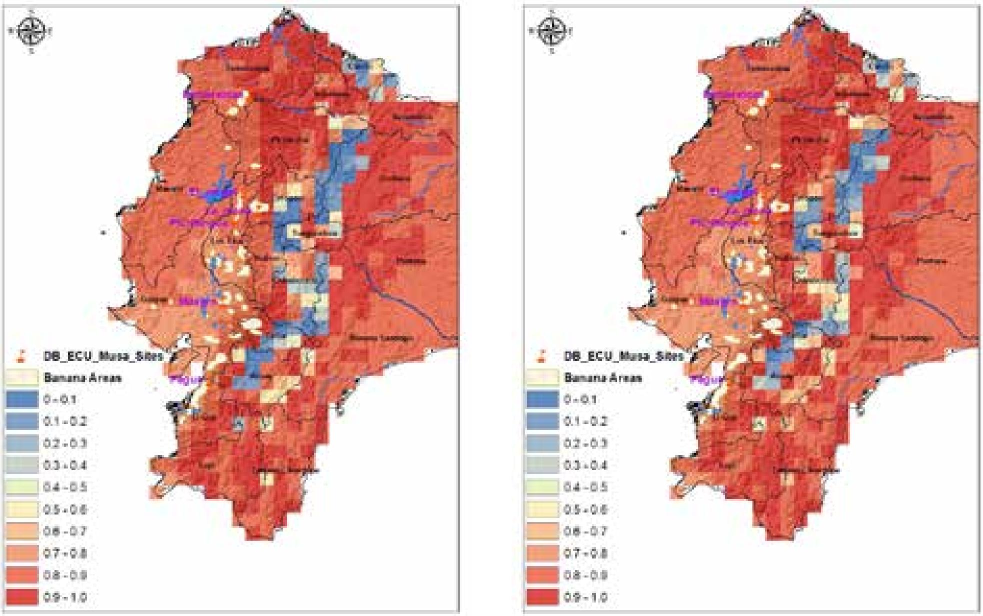
To visualize the variability for the six selected points in coastal Ecuador, the monthly data from 1950 to 2009 was graphed as a function of the average for the period 1960-90. The resulting Figure 25 locates a data point for each year above or below the average temperature and rainfall for the reference period. The points which are closer to the centre point 0/0 are years that more closely reflect the average climate. Points which are close to the average are found within the blue box, with less than 25 percent variability in rainfall and ±1°C in temperature. The points outside the blue box - but inside the yellow box - show moderate variability from the average year with ±25 percent to ±75 percent in precipitation and with temperatures above ±1°C and less than ±1.5°C. Those points outside the yellow box are extreme years - either extremely wet or dry or extremely hot or cold. For Pichilingue, the extreme years (1983 and 1998) are El Niño years (NCAR, 2013).

Figure 24 Establishment index for current conditions and projections for the years 2030, 2050 and 2070 for *C. Sordidus*



Current

2030

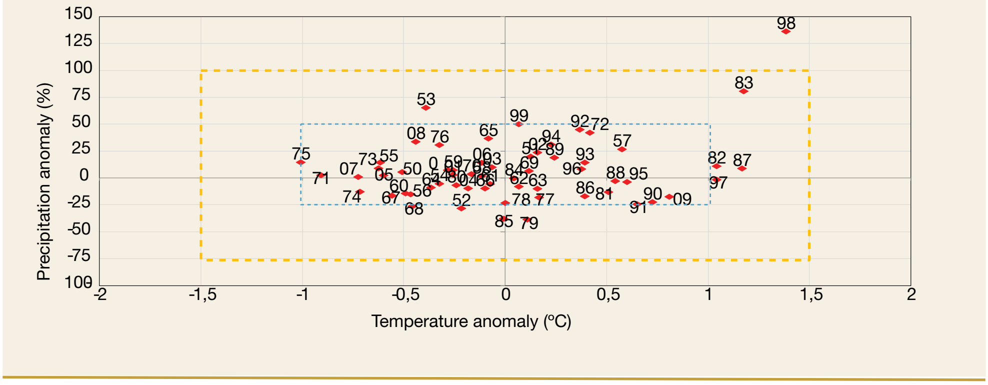


2050

2070

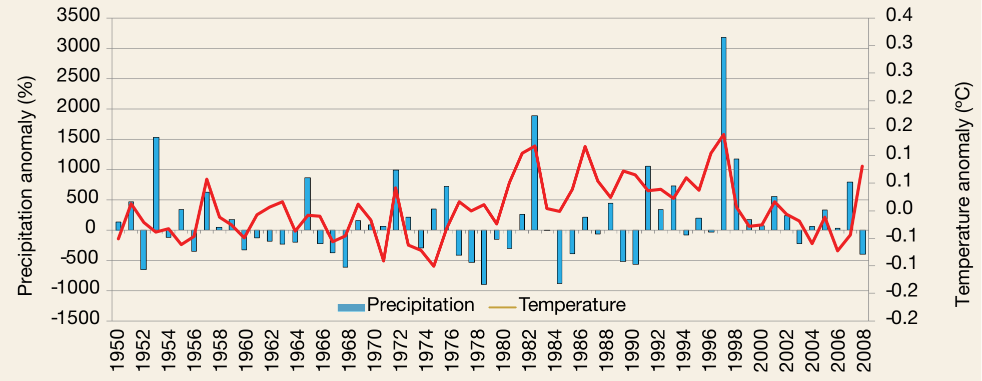
Source: Author's calculations

Figure 25 Pichilingue's historical variability - annual average precipitation and temperature (1960-1990): 2000 mm and 22°C, respectively



Source: Own elaboration, based on CRU data

Figure 26 Pichilingue's annual variability for precipitation (2000 mm) and temperature (22°C)



Source: Authors' elaboration, based on CRU data

These same data for the period 1950-2009 can be viewed chronologically (Figure 26) in relation to the average for the period 1960-90. Blue bars are years with rainfall above 2 000 mm and orange bars are years with below-average rainfall. The extreme nature of El Niño years is evident. For example, in 1998 over 5 000 mm of rainfall fell, when average rainfall is around 2 000 mm, while in 2003 rainfall was 3 500 mm. The red lines show annual average temperature. The early years had below-average temperatures, followed by a period of 18 years above average and, more recently, a cooler period.

Figures for the other five stations (Figure 27) show similar patterns. El Niño years stand out as extreme years for all six sites, even though average rainfall varies from 790 mm in the south to over 2 500 in the north. The northernmost site in Esmeraldas stands out with a different pattern for the moderately variable years.

The variability analysis was also applied to specific critical seasons. In the case of coastal Ecuador, the rainy season begins in mid-December after a period of five to six months of dry weather. The rains intensify quickly and continue through the end of April and then decline through June. The period from July to November is dry. The months of July and August, however, bring clouds and cool weather which reduce banana growth while, from September, temperatures increase as clouds dissipate. By December, the rains begin again. This average pattern, nevertheless, shows variability from year to year. Two periods of the year were selected as a focus for seasonal variability. The cool season during July and August requires changes in management and it reduces production, while the rainy season brings more favourable conditions for plant growth, but also for leaf diseases.

Three of the six points were selected for this analysis of seasonal variability (Table 16). The drier site to the south, Pagua, shows greater percentage variability in the rains during the rainy season than the intermediate site, Pichilingue. The northern site in Esmeraldas has most of the points within the blue box indicating that rainy season weather is not highly variable, although all three show similar extreme outliers. For the cool, dry season, variability is high for all sites for rainfall and temperature. Extreme high temperature years for July and August were more frequent in Pagua and Esmeraldas on the northern and southern extremes. In some cases, these extreme years with high temperatures may result in greater productivity, since the average cool temperatures and cloud cover reduce plant performance. Pagua had a greater frequency of moderately extreme low temperature events for July and August over the registered period. In these years, productivity will be even lower than normal (Figure 28).

This variability in the weather during the rainy season and the dry season is a challenge to banana growers to maintain crop productivity and quality, to meet contracts for volumes of fruit and to control costs. As the focus groups indicate in later sections, this variability is of greater concern for growers than the climate change projections to 2030, 2050 and 2070.

2.5 Projected changes in climate in upper watersheds flowing into banana production areas

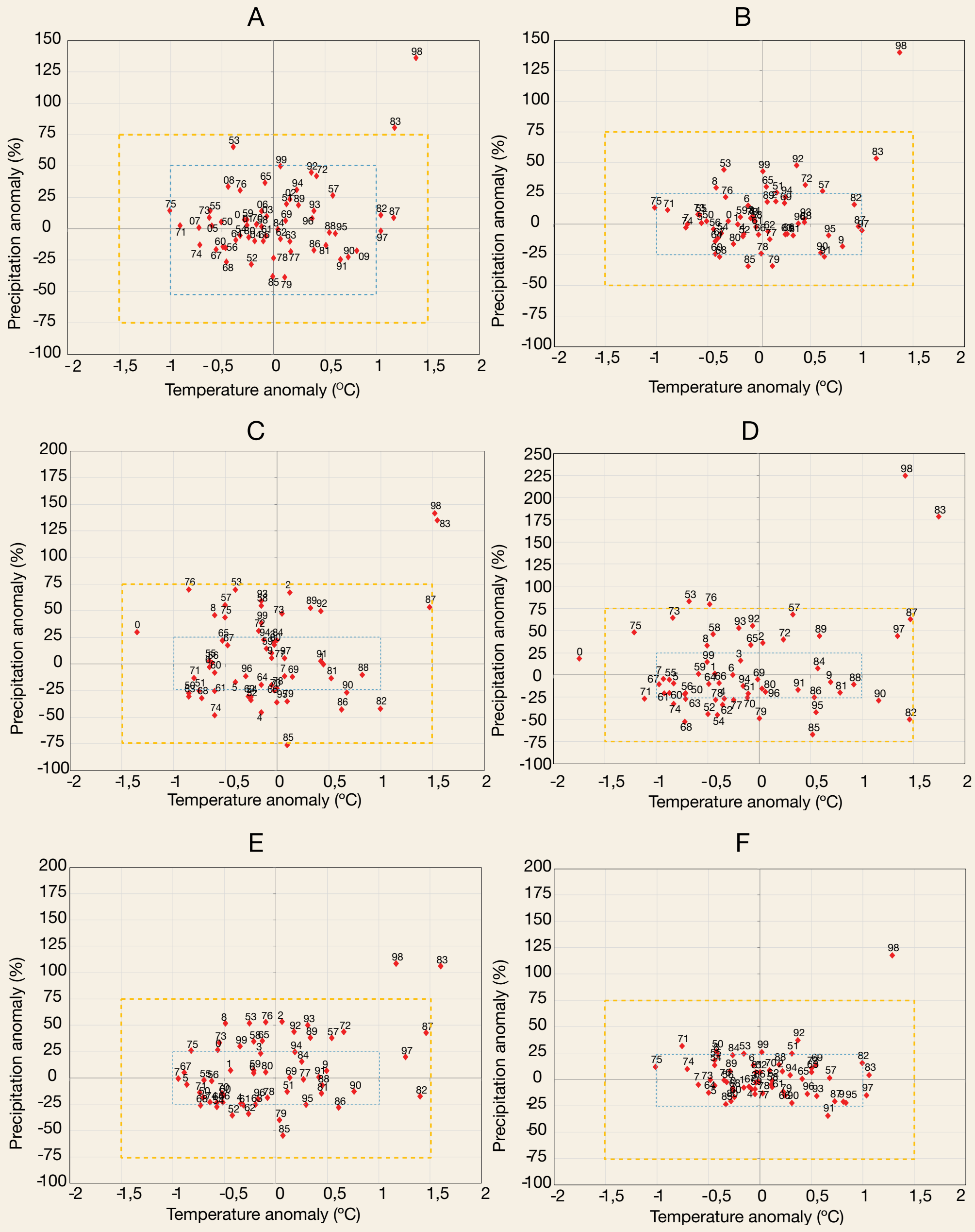
The principal banana growing areas of Ecuador in El Oro, Guayas and Los Rios indicate high seasonality, with an extended dry period when irrigation is

Table 16 Puntos representativos para determinar la variabilidad estacional

Location	Agro-climatic zones	Description
1. Provincia de Esmeraldas	432	>2 500 mm, >24°C, <3 dry months
2. Pichilingue (Los Ríos)	331	1 500-2 500 mm, >24°C, >3 dry months
3. Pagua (El Oro)	131	<900 mm, >24°C, >3 dry months

Source: Authors' elaboration, based on temperature and precipitation data from WorldClim (Hijmans *et al.*, 2005).

Figure 27 Historical variability (in parentheses*, annual precipitation and annual average temperature, respectively) *



Source: Authors' elaboration, based on CRU data

*: A: Pichilingue (2 000 mm; 22°C), B: El Vergel (2 460 mm; 22°C), C: La Mana (2 300 mm; 22°C);
D: Milagro (980 mm; 26°C), E: Pagua (790 mm; 22°C), F: Esmeraldas (2 500 mm; 25°C)

Source: Authors’ elaboration, based on CRU data
*:

essential. In an analysis of the implications of climate change for the banana sector, consideration should also be given to the source of irrigation water. How will these areas be affected by climate change? Are these changes positive and negative for the water needs and growing conditions of banana plantations down river?

The watershed of the Babahoyo River originates in the Andes and reaches the lowland where it joins the Guayas River. About 38.3 percent is subject to flooding (Noboa 2014). The average annual precipitation is approximately 2 300 mm, 300 mm greater than the lowlands. The projected average climate change in the upper watershed follows the pattern for the banana sites reviewed earlier (Figure 29). The rainfall distribution remains the same, with a slight increase in overall amount in most months of the year. Temperatures are also projected to increase, following a similar pattern as in the lowlands. In terms of variability (Figure 30), extreme years are linked to El Niño (CPC, 2014). However, most of the points are found within the blue box, indicating a relatively stable climate from year to year. The frequency of extremely wet years is higher than the frequency of extremely dry years (Figure 31). If this pattern continues in the future, the problems of floods, made more severe due to deforestation and other land use changes, would appear to be a greater threat to banana productivity than the availability of water for irrigation.

2.6 Implications of climate change and weather variability for export banana production

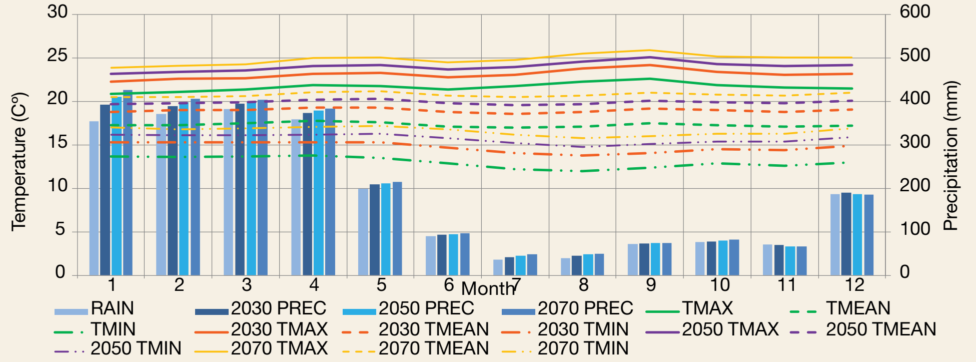
The yield, productivity and quality of banana production are influenced by numerous interactions in the banana agro-ecosystem. The banana plant itself responds to available sunlight, temperature, water and nutrients which may vary throughout the year. The banana plant is also a host to many organisms above and below ground - beneficial and parasitic - which are also influenced by light, water, temperature and nutrients. In addition, the organisms living off the banana also serve as nutrients and energy for other organisms. To date, banana scientists have not been able to capture banana growth and productivity and the dynamic of the food web into a single model to project the resulting responses of banana to climate change. Diverse tools have been used here to develop a more complete perspective on the implications of climate change for banana, as presented in the previous sections. Below, these implications are summarized into abiotic and biotic factors and weather variability.

2.6.1 *Abiotic conditions: temperature and rainfall*

Through 2070, average climatic conditions will continue to be favourable for banana production in the primary production areas for bananas in Ecuador. The growth cycle from sucker emergence to flowering will shorten as a result of increased temperatures. This may result in smaller bunches, but more bunches per hectare per year with yields relatively stable.

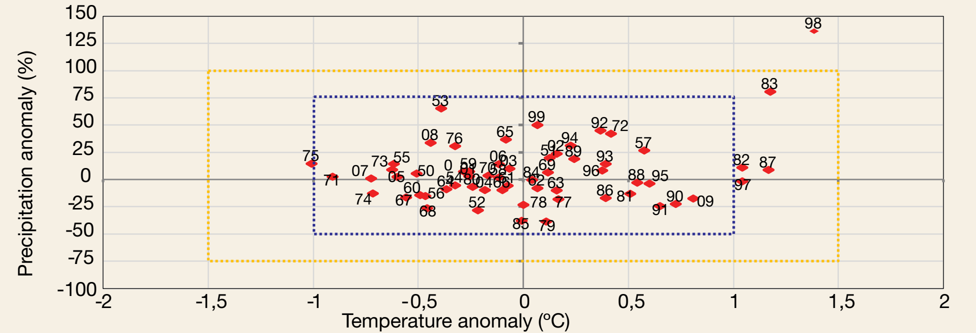
Increasing temperatures in the cool season during July and August should favour increased productivity compared to the current temperature regime. The

Figure 29 Climate change projections for the upper watershed of Babahoyo *



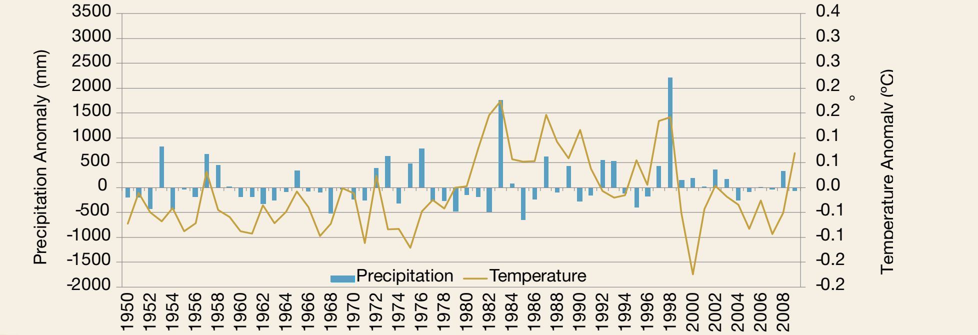
Source: Authors' elaboration, using average values for 20 GCMs under scenario A2

Figure 30 Variability for the upper watershed of Babahoyo - average precipitation and temperature (1960-1990): 2 300 mm and 20°C, respectively



Source: Author's elaboration, based on CRU data

Figure 31 The frequency of extremely wet and extremely hot years



Source: Authors' elaboration, based on CRU data increase in temperature during the rainy season will remain within the optimum range. Short heat waves of excessively high temperature appear unlikely.

As a result of higher temperatures throughout the year, bananas will have an increased demand for water, reaching 12-15 percent increase over current conditions by 2070. This demand for water will be primarily in the dry season. No changes in the distribution of rainfall during the year are projected, with only slight increases in the amount of rainfall in certain rainy season months.

In summary, the average climate change projected for coastal Ecuador may require some adjustments in production practices. It does not, however, appear to present a major threat to sector productivity.

2.6.2 *Biotic condition: pests and diseases*

Month-to-month rainfall distribution is not projected to vary even through 2070, although temperatures are projected to increase. Since the dynamic of BS is not highly temperature-dependent but more linked to leaf wetness, little change is projected in the BS rate of evolution due to average climate change.

Increased temperatures, however, may result in an increase in the velocity of the growth of the BS spore germination tube and a resulting increase in the aggressiveness of the disease. Since fungicide applications are timed primarily to protect new leaves, increased fungicide application frequency may result from the increased leaf emergence rate.

Pests, such as nematodes and stem weevils, will have accelerated growth with higher temperatures, which will lead to shorter cycles of reproduction and a greater potential for damage with more explosive populations. However, very little is known about the longevity response of adult weevils and nematodes. Shorter life cycles in response to higher temperatures could potentially serve to dampen pest response to increased temperatures. In addition, little information is available on the temperature response of the natural control agents of weevils and nematodes. Increased activity in response to climate change by *Beauvaria bassiana* or predatory nematodes could compensate the potentially more explosive weevil or plant-parasitic nematode populations.

In summary, while simple models suggest that pests and diseases will not have an outsized response to the project change in climatic averages, the interactions of the crop-pest/disease beneficial organisms need to be studied. These studies will require greater depth to predict with greater understanding their response.

2.6.3 *Weather variability*

Current variability in weather from one year to the next represents an important factor in the management of the banana. Certain types of extreme and moderate events are easier to address through management than others. The excess rains associated with El Niño of 1998 resulted in far more disruption than the unusually high temperatures during July and August in certain years, which actually may have increased banana productivity.

The potential for increasing frequency of moderate and extreme weather variability is a large unknown in projections. An increased frequency of years, such as 1983 and 1998, would seriously challenge the stability of the banana sector.

2.6.4

3. Current grower approaches to banana management under extreme and moderate weather variability

On a daily basis, banana growers experience the effects of weather on production. Crop management, under the conditions of variability described in earlier sections, challenges grower capacity to organize production inputs in a timely fashion and to maintain yield, quality and profitability. A future which includes changes in average climatic conditions and, potentially, an increase in weather variability will further challenge grower management capacity. To gain insight into the views and experience of growers in September 2013, five focal groups were organized under the title, "**Banana Growing under Climate Change and Weather Variability – How Do We Better Prepare Ourselves?**" These groups were convened in collaboration with INIAP through the major grower organizations in production zones in four of the major banana growing areas of Ecuador to gain insight into grower perceptions and strategies about climate change.

3.1 Documenting grower strategies

Five groups were convened along the transect from North to South (Figure 17). In El Carmen to the far North, the Federación Nacional de Productores de Plátano del Ecuador (FENAPROPE) convened plantain growers from the principal zone for this crop. These small-scale growers produce without irrigation and with low levels of off-farm inputs in a region highly favourable to plantain production. The other zones farther to the South produce conventional and organic bananas with irrigation, high levels of off-farm nutrients and chemical and organic inputs for pest and disease management. In Table 17, the most common responses about management strategies from the growers are highlighted and the percentage of participants, who indicate it as a main activity, are within parentheses. Each group offered their view about climatic variability during recent decades (Table 18). The views were quite different from group to group. Two groups felt that each year is different, while another group viewed variability as occasional. Two groups expressed that there was little variability in climatic conditions.

In response to a question about the type of weather in the recent past which disturbed yields and management practices, growers identified factors which were common across all zones: early or delayed start or finish of rainy season; increase or decrease in expected rains in the rainy season; and higher or lower temperatures and sunlight during July and August. Other factors were specific to certain zones: floods, landslides, volcanic ash, and shortage of irrigation water from rivers which depend on rainfall (Table 19).

Each group traced out the normal seasonal pattern of temperature and rainfall fluctuation, locating events of variability in each season. The two seasons represent highly contrasting conditions with quite different levels of production (Table 20). The decrease in boxes of fruit/month may reach 30-50 percent during the period of cold and low light. Even though growers identified a clear annual pattern for weather, the beginning and end of the rains marks an important source of variation (Table 21). The rainfall amount also varies (as was also seen in the analysis of historical records). The period most mentioned as a source of routine variability is the cool, cloudy period in July and August, which may be less marked in some seasons than in others.

The normal weather pattern can be completely upset in the years representing El Niño or La Niña. The frequency of such years was also seen in Section 2.3. El Niño brings heavy to very heavy rains in the rainy season, which can also carry over to the dry season with major consequences for banana leaf diseases. Increased temperatures in the period of cold and low light increase leaf emission rates and production, and they reduce the need for irrigation. Low-lying production areas are subject to highly destructive floods and landslides. Several groups also identified years of increased cold and more extended cloudiness as a case of extreme events. Although such conditions are common every year to some extent, in some years, such as 2013, the cold temperatures and cloudiness persisted over a longer period with negative consequences for production. In zones on the southern extreme of the transect, droughts during the normal rainy season were also identified (Table 22).

Banana growers in each group described the changes in management which they employ to maintain production and quality and reduce the adverse effects of problematic weather. Obviously irrigation and drainage are key practices, although not among the small plantain growers of El Carmen. The management of BS, including fungicide applications and cultural practices are applied, depending on normal and exceptional rainfall. Depending on the zone, growers adjust their use of fertilizers. In El Carmen fertilization is only done in the rainy season, while among export growers they reduce fertilizer applications in the rainy season to reduce losses. Just prior to the cool, cloudy period, banana growers adjust practices to stimulate and maintain growth during the unfavourable conditions - soluble fertilizers in irrigation water, foliar nutrient applications and the application of micro-organisms to the soil. Bunch management is also adjusted by season. More hands are removed just after bunch emergence during periods of less favourable growth (cold, limited light, dry season). The type of bag used for the bunch also varies by season - with fewer perforations in the bag during the cooler weather. No practices were mentioned to reduce the effects of wind (Table 23).

3.2 Implications of results from focus groups for climate change

Growers recognize that weather variability as a key factor in the productivity and profitabilty of their banana farms. They adjust their management practices in two ways:

- The annual schedule of practices varies as a function of conditions which are present seasonally every year - dehanding, type of bag used for bunches, use of fertilizer.
- Changes in practices, which correspond to the changing weather conditions from year to year, are primarily linked to the use of fungicides and cultural practices for BS control and frequency of irrigation.

Research could contribute to management strategies following the proposed categories of response, presented in Section 2.6. These include:

- plant genetics: grower applied clonal selection to identify plant types suited to the particular conditions of the Ecuadorian coastal plain;
- plant population (buffering): feasibility of sucker management to offset seasonality of productions,
- plant population (recovery): practices useful to recover production after debilitating extreme events, such as floods, extreme cold and severe droughts; and
- field agro-ecosystem (buffering): practices to build root health for efficient use of nutrients and water.

Research, using a socio-ecological perspective, could also address opportunities for local and regional landscape approaches. In addition, it could include approaches to building social capital to identify practices which ensure protection of key production areas from extreme events (Table 15), build buffering capacity in watershed management and develop scenarios for efficient and low-cost recovery of production and marketing potential.

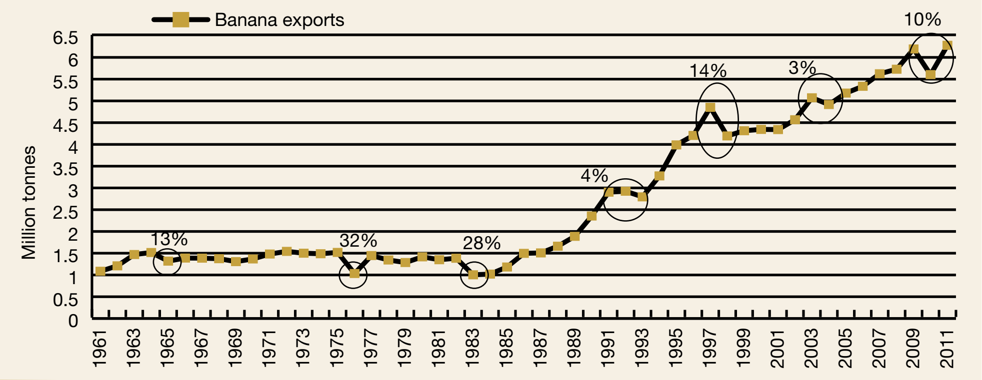
4. Review of disruptive effects of moderate and extreme climate events on Ecuador's banana trade

To establish whether climate change has the potential to disrupt global banana markets, a desk study was conducted, linking annual declines in volumes of bananas exported to possible causal factors. Data on volumes exported were taken from FAOSTAT for the period 1961-2011 and graphed. Based on the graph, six major declines were identified (1965, 1973-1976, 1983, 1993, 1998, and 2010) (Figure 32). For each of the declines, secondary information was compiled from web sites of international trade organizations and national public and private institutes. The causes were classified by type of event: political, economic, climatic and others.

A similar analysis was conducted for Cameroon, Colombia, Costa Rica, Côte d'Ivoire, the Dominican Republic and the Philippines. Price fluctuations for a box of bananas in the EU and United States markets for the period 1992-2009 were also identified and the causes, based on secondary sources, were classified as above. Only the results for Ecuador are presented here.

As can be seen in Figure 17, in 1965 banana exports fell by 13 percent due to a decline in the international price of bananas caused by an increase in supply, mainly due to MNCs having established themselves in Central America and tripling production, as well as expanding operations to the Philippines. This displaced the Ecuadorian banana from Asian markets. Furthermore, the introduction of Cavendish plantations in Central America caused a loss of comparative advantage to Ecuador. Another factor that influenced the decline in exports in 1965 was the disappearance from the Ecuadorian market of corporations, such as the United Fruit Company (now Chiquita), and the decline since 1965 of the Compañía Frutera Sudamericana market share, due to the crisis that started that year, until its complete disappearance in 1981 (Montalvo, 2008; Corporación Editora Nacional, 1987).

Figure 32 Significant declines in annual banana exports for Ecuador from 1961-2011



Source: FAO statistics

Later, in 1973 and 1976, banana exports fell by 3 percent and 32 percent, respectively, caused by high levels of BS that resulted in the abandonment of plantations in 1973 and 1976 due to difficulties in the harvesting process. Both periods coincided with the occurrence of El Niño, the third such phenomenon of its kind in the twentieth century, which came severe impact. Although specific reference of the impact of El Niño on the production or banana exports has not been found, it is known that this phenomenon caused floods and excessive humidity which, at the same time, resulted in the development of diseases caused by fungus, such as BS. This may have been, therefore, one of the factors that influenced the development of the diseases in both periods, reducing banana exports (Arteaga, 2000; Neira 2010; and Ministerio de Salud Pública, n.d.).

In 1982-1983, the El Niño occurrence was one of the most severe events to have affected Ecuador, surpassed only by is occurrence in 1997-1998. The effects lasted eleven months, causing permanent flood destruction of an estimated 10 000 hectares and severely damaging 27 000 hectares. During 1997-1998, exports declined by 28 percent (FAO, 1986).

In 1993, banana exports declined by 4 percent as a result of trade restrictions, imposed by the EU. This also reduced the international commodity price of the Ecuadorian banana (Muñoz, 2000). The El Niño phenomenon of 1997-1998 lasted 19 months. It was continuous, with long-term precipitation, resulting in the worst damage in Ecuador's recorded history. The agriculture sector was the most affected since, at the time, the bananas that had just been harvested did not reach their target markets due to damaged roads and bridges. The new plantations could not be farmed due to the saturation of humidity in the soil (CEPAL, 1998; Neira, 2010; WW2010, 2010; Ministerio de Salud Pública n.d.; Umpierrez, n.d.).

In 2010, banana exports were affected owing to the low temperatures experienced by Ecuador most of the year and to the weak demand from markets, such as Russia and the United States, during the first half of the year. In the case

Table 17 Most common responses from the five focal groups (Taken from the inscription forms)

Plantain

Grower group [*]	**Área** [**] **(ha)**	**Freq. Defoliation** [***]	**Seed material**	**Fertilization**	**Quantity** [****] **(bags/ha)**	**Soil analysis**	**Labour cost records**
El Carmen (17)	5	15 days (67%)	Sel suckers own farm (76.5%)	Chemical fertilizer (41%)	2	No (71%)	Occasional records (53%)

Banana

Grower group [*]	**Área** [**] **(ha)**	**Irrigation type**	**Water source**	**Prod. type** [1]	**Sigatoka mgmt** [3 2]	**Sigatoka Dry season**	**Soil analysis**	**Freq. soil analysis**	**Foliar analysis**	**Freq. foliar analysis**	**Irrigation** [4]	**Climate data** [5]	**Costs** [6]
Quevedo (19)	59	Sub-foliar (63%)	River (79%)	Conv. (100%)	33	Defoliation, surgery and applications (68%)	Yes (89%)	Every six months (50%)	Yes (79%)	Every six months (46%)	Visual estimation (63%)	Closest weather station (40%)	Account S/W (47%)
Guabo (8)	6	Sub-foliar (100%)	River (71%)	Conv. (71%)	23	Defoliation, surgery and applications (86%)	No (57%)	-	No (57%)	-	Visual estimation (60%)	No use climate data (75%)	No records (66%)
Machala (9)	34	Sub-foliar (89%)	River (89%)	Conv. (100%)	19	Defoliation, surgery and applications (56%)	Yes (56%)	Annually (60%)	yes (67%)	Anual (80%)	Visual estimation (44%)	No use climate data (50%)	Manual accounts (56%)
Guayas (5)	89	Sub-foliar (60%)	Well (60%)	Conv. (100%)	18	Defoliation, surgery and applications (80%)	Yes (100%)	-	Yes (80%)	Cada 2 años (60%)	Scheduled irrigation (80%)	Closest weather station (80%)	Account S/W (100%)

Source: own elaboration, based on data from focal groups

[*] Number of participants per group. [**] Average area planted (ha). [***] Frequency of defoliation to manage Black Sigatoka.[****] Quantity of fertilizer use (bags/ha).

[1] Production type: Conventional (Conv.); Organic (Org.). [2] Average of cycles or applications in a year. [3] Black Sigatoka Management in the dry season [4] Irrigation management strategy.

[5] Records on farm of climate data [6] Records of costs: Accounting software (Account. S/W); Manual accounting (Manual). account) [6] Records of costs: Accounting software (Account. S/W); Manual accounting (Manual).

Table 18 Responses of five focal groups to a question about the variabilty of weather conditions from one year to the next

Grower group (number of participants in parentheses)	Mostly normal years	Every 6-10 years (events which disturb routine management)	Every 2-5 years (events which disturb routine management)	Each year is different
	....	%	....	
1. El Carmen – small plantain growers: FENAPROPE : (17)	0	7	0	93
2. Quevedo – médium banana growers: Aprobanec (19)	0	7	21	72
3. Guabo – banana growers: Asoguabo (8)	100	0	0	0
4. Machala – banana growers (9)	0	100	0	0
5. Guayas – large growers of bananas Agroban (5)	100	0	0	0

Source: Authors' elaboration, based on data from focal groups

of Russia, exports decreased by 2 percent during the first six months of the year, when Russian demand shifted to Costa Rica as a source of bananas. Exports to the United States were 3 percent lower in the same period (Freshfruitportal.com, 2010; Marco Trade News, 2010; Frutrop online, 2010).

In conclusion, four of the seven drops in Ecuador's banana exports - analysed for the period 1961-2011 - are related to climatic events, mainly from floods or low temperatures associated with El Niño and La Niña. Following the weather events, trade restrictions (especially by the EU) and variations in international commodity prices resulted in variations in banana exports (Table 24).

Table 19 Disturbing weather events for production and management of bananas – open responses from growers (% response from total of 5 focal groups)

Group	Mentioned factors and frequency
El Carmen	Drought – 9; cold temperatures – 4
Quevedo	Intense cold/low light – 10; heavy rains – 4; volcanic ash – 4
Guabo	Shortage of irrigation water from river – 2
Machala	heavy rains/floods – 4; winds – 3; high temperatures – 1; low temperatures – 1

Source: Authors' elaboration, based on data from focal groups

Table 20 Average production in boxes/month by season and by zone

	Season			
Zone	Rain	Cold/low light		Increased light and warmer temperatures
El Carmen	80	40	20	30
Quevedo	220	200	120	180
Agroban	240	130		195
Guabo	200	160	120	180
Machala	200	130		160

Source: Authors' elaboration, based on data from focal groups

Table 21 Moderate weather events by season

	Start rains	Main rains	End rains	Early dry season	Late dry season
El Carmen			Early or late end to rains	Increased cold and lower light	Intense light/ few showers
Quevedo	Early or late start to rains	More or less rain	Early or late end to rains	More or less cold	
Guabo		Lower rains		Greater cold	
Machala		Rainy season droughts		Increased cold Niña	
Agroban	Early or late start of rains	Moderate droughts Heavy rains	Early or late end to rains	Intense cold Increase light/ higher temperatures	

Source: Authors' elaboration, based on data from focal groups

Table 22 Extreme events by season

	Beginning of rains	Main rainy season	End of rains	Early dry season	Late dry season
El Carmen					Heavy rains/El Niño
Quevedo		Heavy rains or prolonged droughts		Intense cold	Heavy rains and heat from El Niño
Guabo		Total drought		Heavy rain El Niño	Heavy rains El Niño
Machala		Heavy rains Niño		Heavy rain El Niño	Heavy rains El Niño
Agroban		Dry spells – Excessive light Heavy rain – Niño		Increased light and heat Heavy rains El Niño	Drought and heat Heavy rains El Niño

Source: Authors' elaboration, based on data from focal groups

Table 23 Management adjustments made in response to seasonal changes: focal group results

	Beginning of rains	Main rainy season	End of rains	Early dry season	Late dry season
RAINFED PLANTAIN					
El Carmen		• Fertilization • Dehanding – fewer hands		• No fertilization • Dehanding – more hands	
BANANA					
Cold and low light		• Dehanding – fewer hands • Bag for bunch with more perforations	• Soluble fertilizer with irrigation • Application of micro-organisms	• Soluble fertilizer with irrigation • Foliar fertilizers • Dehanding – more hands • Bag for bunch with fewer perforations • Decreased deleafing with increased partial leaf surgery	• Dehanding – more hands
Heavy rains		• More applications for BS – use of systemic fungicides • Reduced fertilization			• Drainage canal maintenance
Droughts		• Supplementary irrigation • Reduced applications BS			
Winds					

Source: Authors' elaboration, based on data from focal groups

Table 24 Major causes of declines in export banana volumes for Ecuador since 1961

Year	Causes
1965	• International commodity price declined due to global overproduction • Introduction of Cavendish into Central America • Disappearance of trading companies, such as United Fruit Company, and decline in market share of others, such as Compañía Frutera Sudamericana, due to the commodity price collapse early in the year
1973 1976	• Reduction in production due to BS introduction into Ecuador • El Niño
1983	• El Niño
1993	• Import restrictions and quotas by European Union
1998	• El Niño
2010	• Low temperatures from La Niña • Reduction in demand from primary markets – Russia and United States

Source: Authors' elaboration, based on information compiled from web sites of international trade organizations and national public and private institutions


©FAO/Aziz Elbehri

CHAPTER 5:

THE CARBON FOOTPRINT OF ECUADOR’S BANANA

Almudena Hospido and Laura Roibas*

---

* Universidade de Santiago de Compostela, Spain (http://www.usc.es/biogrup/)
Assisted by Trossky Maldonado, local expert, Ecuador

1. Introduction

As part of FAO's work on climate change and food systems, a study was undertaken by its Trade and Markets Division to evaluate the impacts of climate change on Ecuador's banana sector. The study seeks to identify various adaptation strategies to aid governments and stakeholders in their strive to develop measures to minimize the effects of climate change. Within this broad study, this chapter present the findings of a life cycle analysis (LCA) of the banana, with a focus on its carbon footprint.

Ecuador's banana sector was selected owing to its strategic importance within the Ecuadorian economy and the dominant position of Ecuador in global banana trade. According to a report of the *Asociación de Exportadores de Banano del Ecuador* (AEBE, 2011), the banana industry represented a revenue of approximately USD 2 146 million in 2011. The banana is Ecuador's foremost export product and constitutes a third of worldwide banana export, at 2.5 percent of GDP and 23 percent of national exports.

The LCA includes the complete banana value chain, while the study covers the entire supply chain from banana production (including small, medium and large plantations, as well as conventional and organic production systems) to final consumption. It aims to assess the environmental performance of the supply chain and to identify the main contributors to climate change along the system (i.e. hot spots).

2. The banana life cycle: Inventory data and assumptions

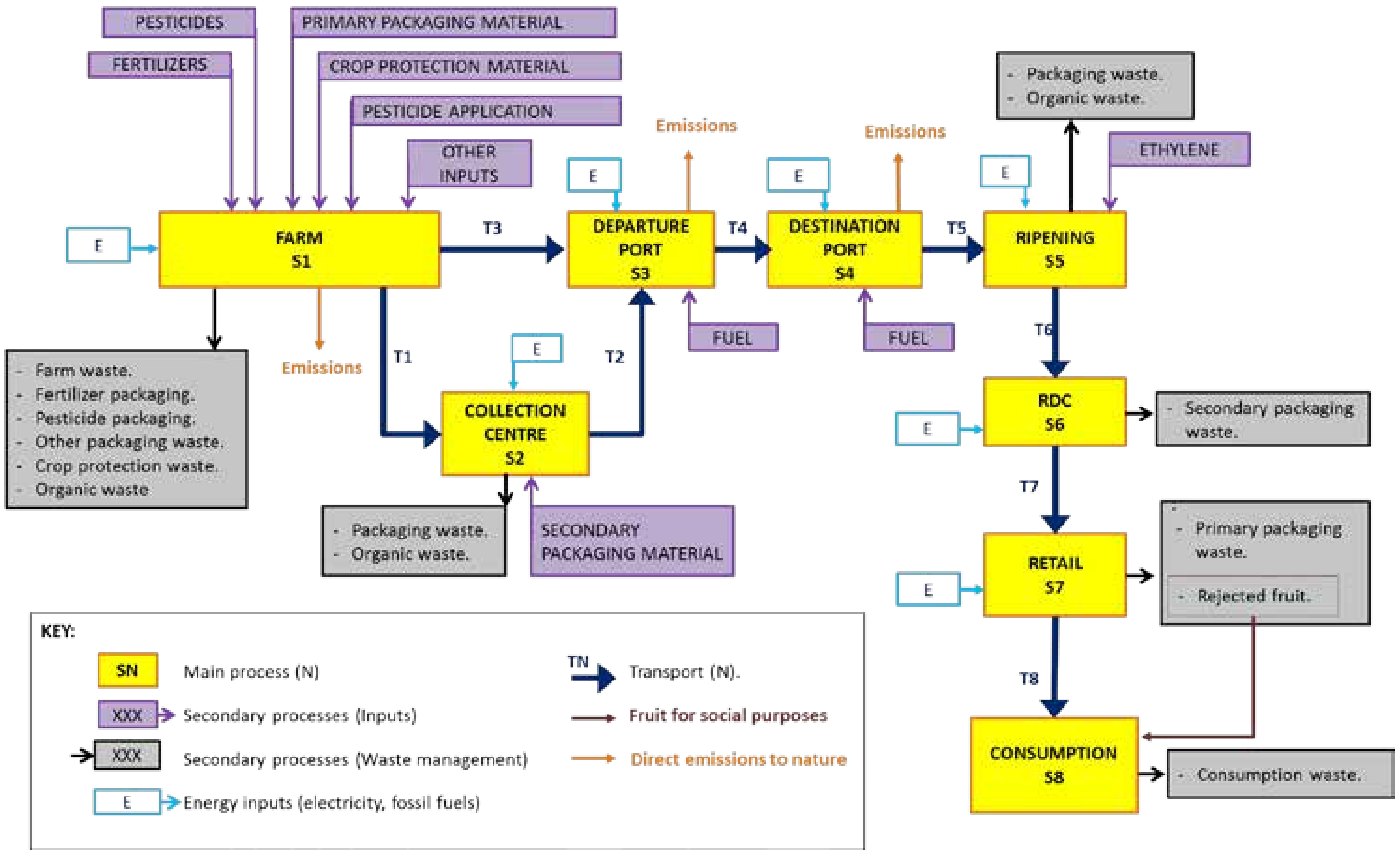
This section describes the inventory data (materials and energy inputs, products, emissions and waste) associated with the various processes that are involved in the banana supply chain. It relates to those processes that take place from the planting of the banana in Ecuador to its consumption in Europe (Figure 33).

A report of the *Asociación de Exportadores de Banano del Ecuador* (AEBE, 2011) indicates that the principal market for Ecuador's bananas is Europe, representing 39.8 percent of total banana exports. Since the ripening, wholesale, retail and consumption stages of the banana supply chain takes place in Spain, this analysis will relate to Southern Europe, and will complement the study by Svanes (2012) in relation to the import of bananas by Germany and Norway and that by Eitner *et al*. (2012) with regard to Belgium, Germany, the Netherlands and the United Kingdom.

2.1 Banana cultivation on the farm (plantation)

The banana plant that is grown in Ecuador is usually the Cavendish variety. The plant propagates and develops from the offshoots of the mother plant and the excess offshoots are removed. The bananas are harvested nine months after planting, when bunches are cut. This procedure is repeated year after year for long periods from the same plant. Various activities take place to ensure that the size of the bunch and the number of bananas per ha is optimal. The organic waste that is generated at the harvest stage (including leaves and shoots) is left on site for natural degradation for soil fertility.

Figure 33 The banana value chain, its stages and boundaries



Source: Authors

Note: The transport component associated with the secondary process (inputs/outputs) is not included, unless otherwise stated.

Since the banana plant requires a significant supply of water, irrigation systems are necessary, either by pumping the water from nearby rivers or by gravity systems. Drainage systems are also used to eliminate excess water in order to provide adequate aeration to the root zone. Bananas require high levels of nitrogen (N) and potassium (K) and, therefore, fertilization is applied according to a programme of recommended quantities and applications.

To prevent and control pests and diseases, aerial spraying and land methods are used. The type of substance and the rate of application will vary, depending on the severity of the disease or type of pest. Agricultural oil and water - and sometimes an emulsifying agent - are used to dilute the compounds to control the pests and diseases.

Subsequent to harvesting, the bananas are covered with plastic to protect the fruit from insects and to guarantee the ripening process. These can be in the form of bags, (e.g. "*daipas*", or bow ties, nun's necks). Once the fruit is harvested, it is manually carried to the processing area on the shoulders of the workers or by cable (Figure 34).

The banana hands are then taken off the stem and put into rinsing tanks for washing. The hands are divided into clusters and placed into another tank, where the latex (released by the bananas) is removed. The clusters then are weighed (Figure 35) and the crowns are sealed, in order to prevent rotting prior to being packed in cardboard boxes (18.14 kilos (kg), the standard capacity for the European market) and loaded onto trucks (Figure 36). The boxes are transported to a collection centre or to the port in refrigerated containers (Section 2.1.2.).

For the purpose of this analysis, 17 plantations (Figure 37) were selected, according to the criteria relating to size and production system (organic and conventional), for which six typologies will be discussed: (i) small organic; (ii) medium organic; (iii) large organic; (iv) small conventional; (v) medium conventional; and (vi) large conventional. Table 25 summarizes their data by typology.

Each of these farms was visited. Interviews were held with the farmer or plantation owner, following the completion of a specifically designed questionnaire.

As opposed to other studies (e.g. Svanes, 2012), where every ten years, an area for banana growing is placed under a six-month fallow period once the plants are removed and the infrastructure has been dismantled, Ecuador's plantations are used permanently for growing in the same area. As a result, the

Figure 34 Banana bunches arrive at the packaging area by cable

©/Authors

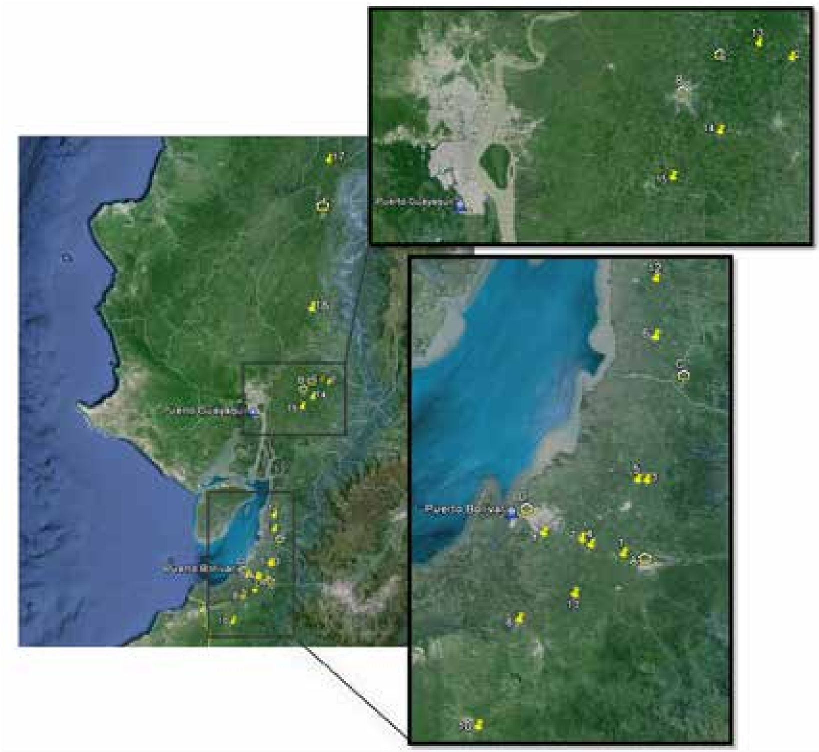
Figure 35 Packaging facilities

©/Authors

Figure 36 Bananas loaded on truck to be transported to collection centre

©/Authors

Figure 37 Geographic distribution of farms, collection centres and ports



Source: Authors

Table 25 General data of the selected farms

Farm characteristics							
Type	Code	Coordinates	Total area (ha)	Average yield (t/ha/a)	Type of banana	Allocated area	Average yield (t/ha/a)
1 Small organic	2	2°05’41,46” S 79°26’41,28” W	5.0	29.0	Giant Cavendish	5.0	29.0
	13	2°04’34,7” S 79°29’24,5” W	5.0	39.6	Giant Cavendish	5.0	39.6
	8	3°28’15,3” S 79°54’44,7” W	10.5	31.4	Giant Cavendish	10.5	31.4
2 Medium organic	5	3°12’50,14” S 79°49’01,94” W	17.0	27.7	Giant Cavendish	17.0	27.7
	11	3°22’50,58” S 79°54’42,48” W	17.0	31.4	Giant Cavendish	17.0	29.4
	10	3°34’23,52” S 80°03’18,36” W	18.5	44.4	Giant Cavendish	18.5	44.4
	14	2°11’19,9” S 79°32’44” W	31.0	36.5	Giant Cavendish	31.0	36.5
3 Large organic	1	3°19’18,63” S 79°50’22,1” W	78.8	29.0	Giant Cavendish	63.8	30.0
					William	15.0	28.0
	12	2°55’05,92” S 79°47’17,90” W	126.7	28.4	Giant Cavendish	126.7	28.4
4 Small, conventional	4	3°18’29,85” S 79°53’10,16” W	12.0	23.4	Giant Cavendish	7.0	14.7
					Filipino	5.0	28.1
	9	3°17’27,42” S 79°57’21” W	12.0	37.7	Giant Cavendish	12.0	37.7
5 Medium, conventional	16	1°38’55,50” S 79°33’02,22” W	40.0	50.3	Giant Cavendish	29.0	50.3
					William	7.0	50.3
	15	2°11’46,92” S 79°36’38,88” W	60.0	29.6	William	60.0	29.6
	3	3°12’52,56” S 79°48’14,34” W	68.0	39.9	Giant Cavendish	68.0	39.9
6 Large, conventional	7	3°18’07,2” S 79°53’57,36” W	95.0	52.1	Giant Cavendish	45.0	45.5
					William	50.0	57.9
	6	3°00’13,14” S 79°47’21,54” W	100.0	41.1	Giant Cavendish	100.0	41.0
	17	0°43’04,80” S 79°26’06,96” W	283.0	45.6	Valery	143.0	41.2
					William	140.0	50.0

Source: Information collected from the questionnaires sent to farmers infrastructure for irrigation and cable transportation has a long lifespan. For this reason, it has been excluded from the calculations, since its contribution to the evaluation is expected to be negligible.

The measurements of two direct GHG emissions are excluded and, therefore, need to be calculated. These are:

- emissions that relate to fuel combustion (e.g. agricultural machinery, small plane for fumigation, lack of electrical pumps): the emission factors reported by Luske (2010) have been applied (2.68 kg CO_2eq/l diesel and 2.33 kg CO_2eq/l petrol.
- N_2O emissions relating to fertilization and the degradation of organic residues: the IPCC guidelines were adapted in this study to tropical soils.

The provision of materials (in particular, fertilizers[36] and pesticides) has been included, since the great majority derive from Europe, according to one of the main distributors (Syngenta) and data from Ecuador's national statistics.[37] Due to the lack of more detailed information, it is assumed that the average distance covered by a cargo ship from Ecuador for all products is 11 000 km.

2.2 Transportation off-farm

a) Transport from the plantation to the collection centre

On some farms in Ecuador, the packaged fruit leaves the plantation in a non-refrigerated truck for transport to a collection centre before it is delivered to the port for export. According to the farmers interviewed within the proximity criteria, there are six collection centres (Figure 37): Pasaje in El Oro Province (A), Guayas Province (B), Azuay Province (C), Machala in El Oro Province (D), Guayas Province (E) and Quevedo in Los Ríos Province (F). The associated GHG emissions will depend on the distance and the size and load of the truck used (Table 26).

b) Collection centre

At the collection centre, the boxes are palletized (48 boxes per pallet). Pallets are assumed to be reused 20 times (FAO, 2013). In addition, four cardboard corners and 40 metres (m) of polypropylene strapping bands are used to secure the boxes on the pallet. One banana box is estimated to be damaged during each boarding activity (i.e. approximately 10 pallets), representing 0.20 percent of loss.

Several sources have been used for the calculation of energy use at the collection centre (Table 27), where an average facility (Martínez, 2009) has been considered. The facility includes a non-refrigerated industrial unit with 200 m^2 of surface and an annual capacity of 2 000 tonnes of banana without a mechanical aeration system.

Table 28 summarizes the material and energy inputs and outputs that repesent this stage. These are expressed as per tonne of bananas entering the collection centre.

---

[36] Except those that are naturally produced, such as compost, poultry manure, molasses and castor-oil plant flour

[37] See http://www.portal.bce.fin.ec/vto_bueno/seguridad/ComercioExteriorEst.jsp

Table 26 Inventory data: transport from plantation to collection centre

Plantation	Collection centre	Distance (km)	Real loaded cargo (tonne)	Average load* (tonne)	Ecuadorian port
2	B	19.4	2.90	3,27 (truck 7,5-16t)	Guayaquil
3 (Europe)	A	19.5	27.08	11,68 (truck >32t)	Puerto Bolívar
4	A	11.3	7.74	11,68 (truck >32t)	Puerto Bolívar
5	A	18	9.67	11,68 (truck >32t)	Guayaquil
6 (Europe)	C	8	83.16	11,68 (truck >32t)	Puerto Bolívar
7	A	11.9	88.96	11,68 (truck >32t)	Puerto Bolívar
8	A	31.1	5.80	5,76 (truck 16-32t)	Puerto Bolívar
			3.87	3,27 (truck 7,5-16t)	Puerto Bolívar
9	D	6.4	9.28	11,68 (truck >32t)	Guayaquil
10	A	54.9	9.67	11,68 (truck k>32t)	Guayaquil
11	A	22	9.28	11,68 (truck >32t)	Puerto Bolívar
12	C	15	46.42	11,68 (truck >32t)	Puerto Bolívar
13	E	9.6	3.87	3,27 (truck 7,5-16t)	Guayaquil
15	B	17.3	29.98	11,68 (truck >32t)	Guayaquil
17 (Asia)	F	36.5	50.28	11,68 (truck >32t)	Guayaquil

Source: Data from questionnaires, Google Maps and EcoInvent database (Spielmann *et al*., 2007).

Table 27 Sources used for the calculation of energy use at the collection centre

Kilowatt hour (KWh)/area unit		Consumption (kWh/tonnes banana)		Commentary
34[1]	kWh/m^2/a	3.40	kWh/tonnes banana	
6,10[2]	kWh/ft^2/a	6.56	kWh/tonnes banana	Value selected for this study
13,93[3]	kWh/ tonnes banana	13.93	kWh/tonnes banana	Includes banana washing and conveyor belt use

Sources: [1] Chadderton (1991); [2] Business Energy Advisor (2013); [3] Luske (2010)

c) Transport from collection centre to port of departure

Once the fruit is palletized, it is transported to the port for export. Interviews indicate that two different types of transport are used for this activity (Table 29). These are non-refrigerated trucks with a maximum capacity of >32 tonnes and refrigerated containers (TEU[38]) trucks.

---

[38] TEU = 20-foot unit. The container has the following standard dimensions: 6.1 m (length) x 2.4 m (width) x 2.6 m (height) and 38.5 m3 volume and stores up to 10 pallets (48 boxes each), totalling 8.71 tonnes of bananas.

Table 28 Inventory data: collection centre

Inputs			Outputs		
Item	Amount		Item	Amount	
Bananas in boxes	1.00	t.	Palletized bananas[3]	0.998	t.
Pallets[4]	0.06	u.	Waste sent to landfill[3]	2.153	kg.
Cardboard corner protectors[1]	4.59	u.			
Polypropylene bands[1]	45.94	m.			
Electricity[2]	6.55	kWh			

Sources: [1]Estimation from video (https://www.youtube.com/watch?v=b6d2J1V_ZUw); [2] Business Energy Advisor (2013); [3] Author's calculations; [4] FAO (2013)

Table 29 Inventory data: from the collection centre to the port of departure

Collection centre	Port of departure	Distance (km)	Type of transport
A	Puerto Bolívar	26.7	Non-refrigerated truck
A	Guayaquil	192	Container reefer truck (TEU)
B	Guayaquil	57.8	Non-refrigerated truck
C	Puerto Bolívar	49.3	Non-refrigerated truck
D	Guayaquil	198	Container reefer truck (TEU)
E	Guayaquil	64.9	Container reefer truck (TEU)
F	Guayaquil	184	Container reefer truck (TEU)

Source: Data from questionnaires and Google Maps

d) Transport from plantation to port of departure

Instead of going through the collection centre, some farms send the fruit directly to the port of export. Refrigerated container (FEU[39]) trucks are used for this activity (Table 30).

e) Port of departure

At the Puerto Bolivar or Guayaquil harbours, the fruit is loaded onto the ship's deck or onto the pallets that are located in the refrigerated hold. The energy inventory data that are associated with this stage (Table 31) include the electricity and fuel (*Terminal Puerto Arica*, 2011) used for the port's loading equipment (mainly cranes), as well as the direct GHG emissions relating to the combustion of the fuel that is used (Luske, 2010).

f) Sea transportation

The main departure ports in Ecuador are Puerto Bolívar and Guayaquil (Table 32), from which an average has been calculated to establish the distance to the

---

[39] FEU = 40-foot unit. It is equivalent to 2 TEU units (i.e. 17.42 tonnes of bananas).

Table 30 Distances covered from the plantation to the port of departure

Farm	Port of departure	Distance (km)
1	Guayaquil	196
3 (Japón)	Guayaquil	173
6 (Japón)	Guayaquil	146
14	Guayaquil	63.3
16	Guayaquil	99.6
17 (Europe, America)	Guayaquil	220

Source: Data from questionnaires and Google Maps

Table 31 Inventory data: port of departure (per tonne)

Inputs			Outputs		
Item	Amount		Item	Amount	
Fuel: diesel[1]	0.59	l diesel	Fuel combustion GHG emissions[2]	1.58	kg CO_2
Electricity MV[1]	2.70	kWh			

Source: [1]Terminal de Puerto Arica (2011); [2] Luske (2010)

Table 32 Export distribution and distances covered

	Export Distribution	Distance to Rotterdam (km)
	%	
Puerto Bolívar	27.26	10.536
Puerto Guayaquil	72.74	10.564
Ecuador		10.556

Source: AEBE (2013)

destination port in Europe (Figure 38). Rotterdam in the Netherlands has been selected as the main European port of entry, according to the shipping companies that were interviewed. It is also a prominent world port.

g) Port of entry

Table 33 indicates the data inventory between the port of departure and the port of entry. This includes the energy (Green Cranes, 2011) and the related GHG emissions as outputs of fuel combustion (Luske, 2010).

h) Transportation from the port of entry to ripening facilities

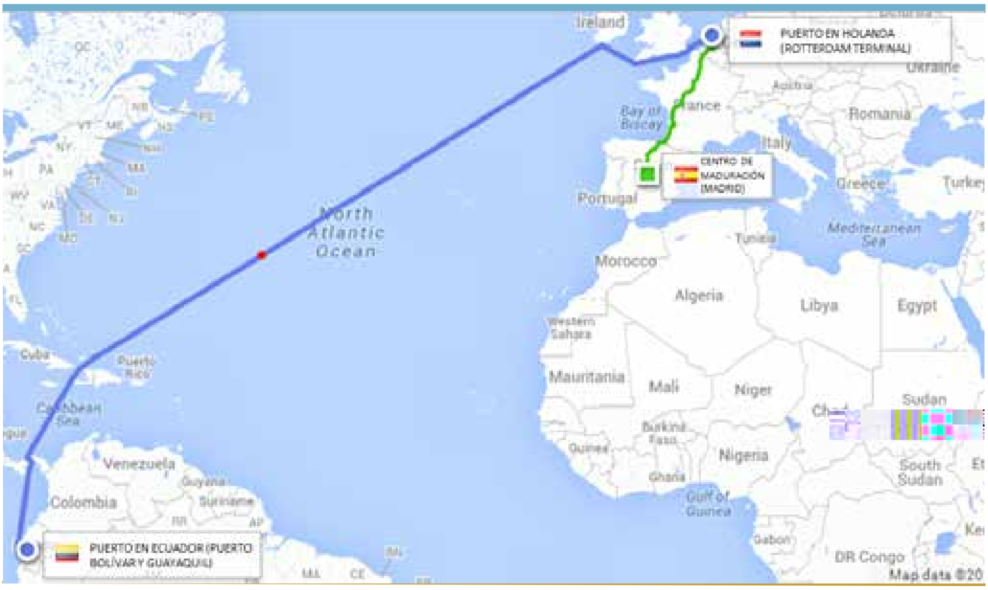
To avoid early ripening, the banana fruit is transported in refrigerated trucks (>32 tonne) to ripening facilities. For this study, the location for ripening is

Table 33 Inventory data: port of entry (per tonne)

Inputs			Outputs		
Item	Amount		Item	Amount	
Fuel: diesel[1]	0.37	l diesel	Fuel combustion emissions[2]	0.98	kg CO_2
Electricity MV[1]	1.38	kWh			

Source: AEBE (2013)

Figure 38 Transoceanic (blue line) and road (green line) transportation to final destination in Spain



Source: http://www.searates.com/reference/portdistance/

assumed as Mercamadrid, near Madrid, Spain, which is the major perishable food distribution complex in the world. Transportation from Mercamadrid to the port in Rotterdam represents 1 714 km. (Figure 38).

2.3 Ripening

The bananas are collected in Ecuador when they are still green and ripening take places at destination under controlled conditions for consistency. Subsequent to a quality control check, the pallets are placed in special rooms where the ripening of the fruit is encouraged by controlled temperatures and the application of ethylene to accelerate the natural ripening process. Biogenic CO_2 is generated during the process and the rooms are ventilated to prevent the concentration of CO_2 from reaching 1 percent, which would hinder the ripening process.

The data for this stage (Table 34) includes the electricity and ethylene as outputs, as well as the wasted bananas (0.52 percent of total bananas during

Table 34 Inventory data: ripening facilities (per tonne)

Inputs			Outputs		
Item	**Amount**		**Item**	**Amount**	
Unripened bananas	1.00	tonne	Ripened bananas[4]	0.99	tonne
Electricity	62.47	kWh	Waste sent to landfill[4,5]	4.12	kg
Ethylene[2]	0.36	kg	Waste sent to incineration[4,5]	1.09	kg
Ethylene bottles[3]	0.04	kg	Plastics sent for recycling[4,5]	0.06	kg
Cardboard			Sent for recycling[4,5]	0.34	kg

Source: [1] Svanes (2012), Luske (2010, Eitner *et al*. (2012); [2] Svanes (2012); [3] Author's calculations; [4] Luske (2010); [5] INE (2011)

Table 35 Waste disposal in Spain

Types of waste	Recycling, Compost	Landfill	Incineration
	....%	....	
Municipal Solid Waste (mixed: black bag)	0.03	78.86	21.11
Paper and cardboard	98.42	1.58	0.00
Plastics	83.11	16.89	0.00

Source: INE (2011)

this stage, in accordance to Luske (2010)). The waste relates to the outcome of quality control and loss during the transportation process, as well as the packaging and ethylene bottles.

In terms of electricity usage, the value that is applied corresponds to the average of the following figures: 0.136 kWh/kg and 0.046 of bananas, reported by Svanes (2012) for Germany and Norway, respectively; 0.066 kWh/kg, reported by Luske (2010); and 0.027-0.039 kWh/kg, reported by Eitner *et al*. (2012).

With regard to the use of ethylene, Svanes (2012) applies between 0.36 and 0.37 g/kg of bananas for ripening in the facilities in Germany and Norway. These figures are in line with the estimates made in this study, based on the volume of the rooms and the concentration required (100-150 part per million (ppm), according to Kitinoja and Kader (2002)). The distribution shown in Table 35 has been assumed for waste management (INE, 2011).

a) Transportation from ripening facility to regional distribution centre

In terms of the distribution of the fruit, the most important RDCs for agrifood products in Spain were selected (Figure 39). Table 36 shows the average distance covered is 300 km by unrefrigerated truck (>32 tonnes).

b) Regional distribution centre

Bananas are palletized upon entering the regional distribution centres, where secondary packaging is removed (pallets, corners and polypropylene strapping

Figure 39 Geographical distribution of selected regional distribution centres

Source: Authors

bands), shown in Table 11 for waste management. The only input is the electricity required for lighting, since no refrigeration is required at this point (Table 37).

c) Transportation from regional distribution centre to retailer

The main cities of the regions selected for this analysis were included in order to calculate the distance between the distribution centre and the retailer (Table 38). Two types of transportation are considered: non-refrigerated truck (7.5-16 tonne capacity and average load of 3.27 tonnes; 70 percent of distribution) and van (<3.5 tonne capacity and average load of 0.19 tonne; 30 percent distribution).

d) Retailer

In Spain, food is sold according to the following distribution: 46 percent in grocery stores, 44 percent in supermarkets and the remaining 10 percent

Table 36 Distances covered from ripening facility to regional distribution centres

From/to	MercaMadrid	Served area
Regional distribution centre I (Ciempozuelos, Madrid)	30 km	Madrid, Castilla La Mancha (North)
Regional distribution centre II (MercaCórdoba)	386km	Andalucía, Extremadura (South)
Regional distribution centre III (Alhama, Murcia)	430 km	Murcia, Castilla La Mancha (South)
Regional distribution centre IV (MercaValencia)	359 km	Valencia, Castilla La Mancha (East)
Regional distribution centre V (MercaZaragoza)	318 km	La Rioja, Navarra, Aragón (North), Cataluña
Regional distribution centre VI (Villadangos, León)	352 km	Galicia, Asturias, Cantabria, País Vasco, Castilla León (North)
Regional distribution centre VII (Zaldesa, Salamanca)	228 km	Castilla León (South), Extremadura

Source: Authors

Table 37 Inventory data for regional distribution centre

Inputs			Outputs		
Item	**Amount**		**Item**	**Amount**	
Palletized banana	1.00	tonne	Bananas in boxes	1.00	tonne
Electricity[1]	6.56	kWh	Waste sent to landfill[2]	1.09	kg
			Waste sent for incineration[2]	0.27	kg
			Cardboard sent for recycling[2]	2.71	kg
			Plastics sent for recycling[2]	0.22	kg

Source: [1] Business Energy Advisor (2013); [2] INE (2011)

Table 38 Summary of the distance covered from regional distribution centre to retailer

From	To	Distance (km)	From	To	Distance (km)
Regional distribution centre I (Ciempozuelos, Madrid)	Madrid	35.9	Regional distribution centre V (MercaZaragoza)	Logroño	179
	Talavera de la Reina	134		Pamplona	183
	Toledo	53.9		Huesca	69.1
	Segovia	126		Lleida	149
	Ciudad Real	171		Barcelona	309
	Average distance	104.16		Average distance	177.82
Regional distribution centre II (Mercacórdoba)	Badajoz	265	Regional distribution centre VI (Villadangos, León)	Santiago	314
	Huelva	232		Ponferrada	95.3
	Sevilla	138		Oviedo	123
	Málaga	164		Santander	280
	Granada	199		Bilbao	349
	Jaén	114		Burgos	195
	Average distance	185.33		Average distance	226.05
Regional distribution centre III (Alhama, Murcia)	Alicante	112	Regional distribution centre VII (Zaldesa, Salamanca)	Zamora	69.7
	Murcia	39.2		Palencia	171
	Cartagena	52.7		Valladolid	127
	Albacete	177		Plasencia	133
	Average distance	95.23		Cáceres	207
Regional distribution centre IV (Mercavalencia)	Teruel	144		Average distance	141.54
	Cuenca	206		FINAL AVERAGE	154
	Castellón de la Plana	78			
	Gandía	69.3			
	Average distance	124.33			

Source: Authors' calculations and Google Maps

Table 39 Electricity and natural gas consumed at retailer

Retailer type	**Area (m²)**	**Av. area (m²)**	**Sales fraction¹**	**Energy use (kWh/m²/a)²**	**Av. energy use (kWh/m²/a)**	**Av. energy use (kWh/t)**	**Natural gas consumption (kWh/m²/a)**	**Av. gas consumption**	**Av. gas consumption (kWh/t)**
Grocery stores	<400	200	0.46	1.500	1212	49.81	0	112.13	4.61
Supermarket	400-2500	1.450	0.44	1.000			200		
Hypermarket	>2500	6.250	0.10	800			250		

Source: ¹ Boletín de información comercial española (2011); ² Tassou *et al.* (2010)

Figure 40 Ecuadorian banana sold in a Spanish hypermarket

©/Authors

in hypermarkets (*Boletín de Información Comercial Española*, 2011). Banana is sold at room temperature in various presentations (Figure 40).

Table 39 includes the energy consumption, taking into account the various types of retailer. Account of the values of electricity and natural gas, reported by Tassou *et al*. (2010), are also taken into account, where the following assumptions have been made: (i) banana is sold in bulk, (ii) one tonne of banana occupies 5 m² of surface and (iii) the fruit remains at the retailer for three days.

On the output side (Table 40), the primary packaging materials are removed at the retailer (i.e. plastic bag and cardboard box) and disposed of, according to the information provided in Table 35. In Spain, 5.6 percent of perishable foods are lost at the retail level (MAGRAMA, 2012); 20.5 percent of this amount is donated to NGOs, assumed for consumption; and the remaining 79.5 percent is discarded. With regard to the current economic difficulties that Europe is facing, however, a significant portion of the discarded amount is being gathered by poor people from the retailer's back door and, therefore, it is assumed to be also consumed. In any event,

Table 40 Inventory data: retailer

Inputs			**Outputs**		
Item	**Amount**		**Item**	**Amount**	
Bananas in boxes	1.00	tonne	Bananas for sale[2]	0.94	tonne
Electricity[1]	49.81	kWh	Bananos for social purposes[2]	0.03	tonne
Natural gas[1]	4.61	kWh	Waste sent for incineration[3]	4.70	kg
			Waste sent to landfill[3]	19.60	kg
			Cardboard sent to recycling[3]	66.19	kg
			Plastic sent to recycling[3]	4.12	kg

Source: [1] Table 15; [2] MAGRAMA (2012); [3] INE (2011)

Table 41 Inventory data: consumption

Entradas			**Salidas**		
Item	**Amount**		**Item**	**Amount**	
Banana	1.00	tonne	Banana peel sent to landfill	316.00	kg
Toilet paper	4.29	kg	Banana peel sent for incineration	84.00	kg
Tap water	13.48	m^3	CO_2 emissions	166.89	kg
Soap	3.57	kg	CH_4 emissions	0.05	kg
Detergent	0.20	kg	Waste water volume	13.83	m^3
Electricity	12.73	kWh			

Source: Muñoz *et al*. (2007)

only 2.24 percent of the bananas that reach this stage are finally disposed of as waste.

e) Transportation from retailer to consumer

Going to shop in grocery stores and supermarkets is assumed to be on foot, an average distance of 2 km, while the distance to hypermarkets is 5 km by car. Bananas represent 1.30 percent of the average weight of a Spanish shopping basket (INE, 2012); therefore, only figure has been assigned.

2.4 Consumption

The end stage of the value chain is the consumption of the fruit (Table 41). In Europe, bananas are stored at room temperature and eaten raw. The main residue is the banana peel, which represents 40 percent of the banana's total weight and follows the waste management distribution presented (Table 35). In addition - and according to Muñoz *et al*. (2007) - the inputs and outputs associated with human ingestion of the banana and its posterior human *excreta* have been included: toilet paper, tap water, electricity, direct GHG emissions and wastewater. Since the waste generated at this stage is significant, its collection and transport to the landfill or incineration plant has been included (Table 42).

Carbon footprint of a given activity =
Activity data (mass/volume/kWh/km) x
Emission factor (CO_2 per unit)

Table 42 Distances and type of transport used for waste management at consumption stage

Waste management	**Route**	**Distance (km)**	**Type of transport**	**Amount**	
Landfill	Farm to collection centre I: Consumption - Landfill	8.5	Collection truck	2.69	tkm
Incineration	Collection centre to departure port: Consumption – Transfer facilities	8.5	Collection truck	0.71	tkm
	Farm to departure port: Transfer facilities – Incineration plant	50	Train	4.20	tkm

Source: Authors' calculations and Google Maps

2.5 GHG emission factors

The calculation of the carbon footprint relating to a product is the sum of all materials, energy and waste across all the activities in the life cycle of the product, multiplied by the GHG emission elements.

Data from the EcoInvent database (Frischknecht *et al*., 2007) have been used in most cases, tailored to the context of Ecuador where necessary. Other sources of information also have been used, as required. This section summarizes some of those modifications relating to emissions.

a) Ecuador's electricity mix

The EcoInvent database provides the elements for individual sources of emission, such as coal and hydropower, as well as the mix relating to several countries; however, it does not do so in the case of Ecuador. Ecuador's national electricity production profile for 2010 (Table 43), therefore, has been defined and the corresponding emission factor calculated as 0.55 kg CO_2-eq/kWh.

b) Local production of cardboard boxes and crop protection elements

A brief questionnaire was sent to two manufacturing companies in relation to cardboard boxes and plastic protection components. The information was applied to the customization of the EcoInvent datasets[40] in relation to Ecuadorian productive systems.

---

[40] "Corrugated board of mixed recycling fibre, single wall and at plant/rer" for the former; "polyethylene, HDPE granules at plant/rer and extrusion of plastic film/rer" for the latter.

Table 43 Ecuador's electricity production profile

Source of emissions	Electricity (GWh)	Electricity (%)
Coal and peat	0	0.00
Oil	7 961	39.54
Gas	2 190	10.88
Biofuels	483	2.40
Hydro	8 636	42.89
Wind	3	0.01
Total production	**19 273**	**-**
Imports	863	-
Colombia	785	3.90
Peru	78	0.39
Total	**20 136**	**100.00**

Source: IEA (2010)

c) Transport in relation to fertilizers and pesticides production

The list of commercial products and brands is constant and, therefore, some simplification was required in order to include all the substances used for fertilization and pest and disease management. In terms of pesticides, the products used at the plantation level have been classified according to the following groups (Table 44):

- substances with emission factors available; and
- substances with emission factors not available:
  a) classified according to particular function (e.g. fungicide, herbicide, insecticide); or
  b) classified as an unspecified pesticide.

A similar procedure was applied in the case of fertilizers, where classification was done on the basis of their formulation (Table 45).

As previously stated, fertilizers and pesticides are mainly produced in Europe and imported by Ecuador by way of transoceanic freight ships. An average distance of 11 000 km has been assumed, resulting in an emission factor of 117.70 kg CO_2eq/tonne of exported bananas.

d) Road transportation

With regard to unrefrigerated transport, emission factors have been applied from the EcoInvent database (Spielmann *et al*., 2007) and these include the environmental impacts associated with the construction, maintenance and operation of the truck, as well as the construction and maintenance of roads. In terms of load, the dataset assumes that the truck is full for delivery and returns empty (i.e. 50 percent of average load).

On the other hand, modifications were required with regard to refrigerated transport, in order to include the extra amount of diesel needed to operate the

Table 44 Emission factors applied in the case of pesticides used during cultivation

Type	**Amount**	**Unit**	**EcoInvent process at regional storehouse/RER[1]**
Fungicide	10.6	kg CO_2eq/kg	EcoInvent fungicides
Herbicide	10.2	kg CO_2eq/kg	EcoInvent herbicides
Growth regulator	7.69	kg CO_2eq/kg	EcoInvent growth regulators
Insecticide	16.6	kg CO_2eq/kg	EcoInvent insecticides
Unspecified pesticide	10.1	kg CO_2eq/kg	EcoInvent unspecified pesticide
Pesticide cyclic N* compounds	15.2	kg CO_2eq/kg	EcoInvent cyclic N-compounds
Pesticide acetamide-anillide-compounds	12.80	kg CO_2eq/kg	EcoInvent acetamide-anillide compounds
Pesticide benzimidazole compounds	3.62	kg CO_2eq/kg	EcoInvent benzimidazole compounds
Pesticide dithiocarbamate compounds	5.27	kg CO_2eq/kg	EcoInvent dithiocarbamate compounds

Source: EcoInvent database (taken from Nemecek *et al*., 2007)

[1] Average data from Europe.

* Nitrogen

refrigeration system. (details of these modifications are available from the authors upon request).

e) Sea transportation

Significant changes were required in relation to transportation by sea, since the emission factors that were available in the EcoInvent database did not match the characteristics of the ships described by the shipping companies interviewed.

f) Waste management: incineration with energy recovery

The EcoInvent process "Disposal, MSW [Municipal Solid Waste], to municipal incineration/CH [Switzerland]" (Doka, 2007) was applied in relation to the waste fraction sent to incineration facilities. Energy that was avoided, however, was included (550 kWh/tonnes of waste)[41] to better reflect European state-of-the-art incinerators.

g) Wastewater treatment plants

The study done by Rodríguez-García *et al*. (2011), in which 26 Spanish wastewater treatment plants were evaluated, was used for the emission factor. This factor related to the treatment of the wastewater, generated from banana consumption at 0. 29 kg CO_2-eq/m^3.

---

[41] See http://www.epa.gov/waste/nonhaz/municipal/wte/basic.htm.

Table 45 Emission factors applied for some of the fertilizers used during cultivation

Type	Amount	Unit	EcoInvent process
Average fertilizer from algae	0.205	kg CO_2eq/kg	EcoInvent lime and algae at regional storehouse/Switzerland
Lime (from carbonation)	0.0116	kg CO_2eq/kg	EcoInvent lime from carbonation at regional storehouse/Switzerland
Potassium chloride	0.497	kg CO_2eq/kg	EcoInvent potassium chloride, as K_2O, at regional storehouse/Average data from Europe
Compost	0.332	kg CO_2eq/kg	EcoInvent compost at plant/Average data from Europe
Ammonium nitrate	8.55	kg CO_2eq/kg	EcoInvent ammonium nitrate, as N, at regional storehouse, Europe
Monoammonium phosphate	2.82	kg CO_2eq/kg	EcoInvent mono-ammonium phosphate, as N, at regional storehouse/Average data from Europe
Diammonium phosphate	2.8	kg CO_2eq/kg	EcoInvent diammonium phosphate, as N, at regional storehouse/Average data from Europe
Ammonium sulphate	2.69	kg CO_2eq/kg	EcoInvent ammonium sulphate, as N, at regional storehouse/Average data from Europe
Zeolite	4.19	kg CO_2eq/kg	EcoInvent zeolite powder at plant/ Average data from Europe
Poultry manure	0.108	kg CO_2eq/kg	EcoInvent poultry manure, dried, at regional storehouse/Switzerland
Potassium nitrate	16	kg CO_2eq/kg	Potassium nitrate, as N, at regional storehouse/Average data from Europe
Phosphate rock	0.226	kg CO_2eq/kg	Phosphate rock, as P2O5, treated and dried, at plant/Morocco
Calcium nitrate	3.85	kg CO_2eq/kg	Calcium nitrate, as N, at regional storehouse/Average data from Europe
Triple superphosphate	2.02	kg CO_2eq/kg	Triple superphosphate, as P_2O_5, at regional storehouse/Average data from Europe
Molasses	0.108	kg CO_2eq/kg	Molasses from sugar beet at sugar refinery/Switzerland
Castor-oil plant flour	0.581	kg CO_2eq/kg	Rape meal at oil mill/Average data from Europe
Urea	3.3	kg CO_2eq/kg	EcoInvent urea, as N, at regional storehouse/Average data from Europe
Ureate (Ammonium nitrate)	5.84	kg CO_2eq/kg	EcoInvent urea ammonium nitrate, as N, at regional storehouse/Average data from Europe

Source: Ecoinvent (Nemecek *et al*. 2007)

3. Interpretation and discussion of results

3.1 The carbon footprint of Ecuador's banana production

The carbon footprint of Ecuador's banana value chain is calculated in per tonne of bananas (unless otherwise stated) from the planting stage to that of consumption. Figure 41 illustrates the banana's carbon footprint relating to the 17 value chains evaluated in this study, as well as the distribution for each stage. The differences relate to the various stages the supply chain in the context of Ecuador (from the farm to consumption), since once the fruit leaves port, the downstream processes remain the same.

The last column of Figure 41 represents the average value, where the extreme results (farms 14 and 15) were excluded due to the values representing direct emissions of N_2O from agricultural soil. On the one hand, the low value for farm 14 is due to the combination of a very low dose of nitrogen fertilizer and sandy soil. On the other hand, farm 15 - where a very high use of fertilizers is combined with a loamy soil - is significantly unfavourable in terms of N_2O emissions. In order to better evaluate the contribution of the various stages, Table 46 indicates the carbon footprint distritution along the banana value chain.

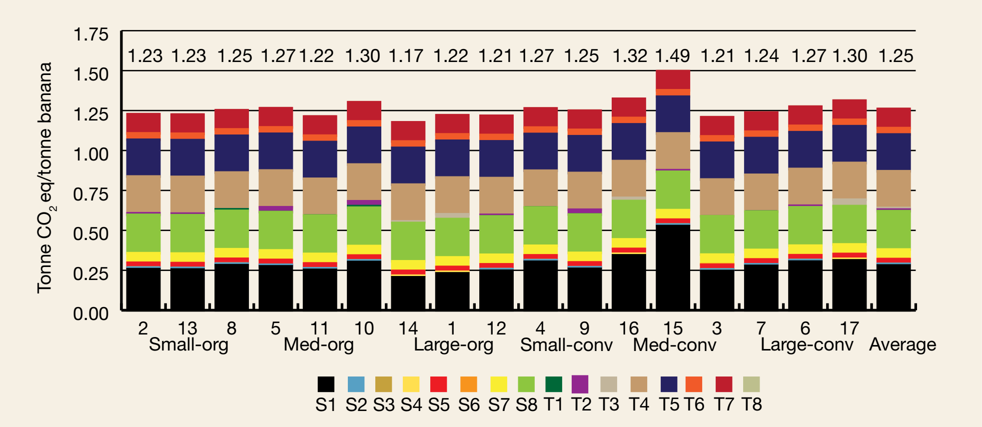
According to the results obtained in this study, the carbon footprint of Ecuador's banana, consumed in Spain, is 1.25 tonne CO_2eq/tonne of banana (0.84 tonne CO_2eq/tonne of banana, excluding consumption). The process excluding consumption, therefore, ends at the RDC stage. Those instances that contribute most to the carbon footprint of the banana include Plantation (22.1 percent average), Consumption (19.2 percent average), Sea Transportation (18.7 percent) and Transport from destination port to ripening facility (18.0 percent).

3.2 Comparison of results with literature

There appear to be four studies that have evaluated the contribution of the banana's carbon footprint to global warming:

- Luske (2010) undertook a cradle-to-gate analysis of Dole bananas in Costa Rica, which are consumed in Germany (the chain ends at the retailer). Data were provided from Dole and two plantations were assessed with information reflecting 2008: Valle de la Estrella and Río Frio. Secondary data and emission factors were derived from several sources and databases, other than that for maritime transportation, which was also provided by Dole.
- The work of Svanes (2012) is based on the previous study, but data also relates to Río Frio for 2009 and 2010. Consumption relates to Norway and results are reported for cradle-to-gate (retailer stage) and cradle-to-grave (i.e. including banana consumption).
- Eitner *et al*. (2012) evaluated five banana plantations in four different countries: Costa Rica (convention), Ecuador (organic and conventional), Panama (conventional) and Peru (organic). The study includes all stages until the RDC stage, and analyses each of the various locations in Europe: Costa Rica's bananas (the United Kingdom); Ecuador's bananas (Belgium, the Netherlands

Figure 41 Final results of the carbon footprint results for the individual and average banana value chains



Source: Authors' calculations

Table 46 Percent distribution of the carbon footprint along the banana value chain

Type	Farm	S1	S2	S3	S4	S5	S6	S7	S8	T1	T2	T3	T4	T5	T6	T7	T8
Small-org	2	21	1	0	0	2	0	5	20	0	1	-	19	18	3	9	0
	13	21	1	0	0	2	0	5	20	0	1	-	19	18	3	9	0
	8	23	1	0	0	2	0	5	19	1	0	-	19	18	3	9	0
Med-org	5	22	1	0	0	2	0	5	19	0	3	-	18	18	3	9	0
	11	21	1	0	0	2	0	5	20	0	0	-	19	19	3	10	0
	10	23	1	0	0	2	0	4	18	1	3	-	18	17	3	9	0
	14	18	-	0	1	2	0	5	20	-	-	1	20	19	3	10	0
Large-org	1	19	-	0	1	2	0	5	20	-	-	3	19	19	3	9	0
	12	20	1	0	0	2	0	5	20	0	1	-	19	19	3	10	0
Small-conv	4	24	1	0	0	2	0	5	19	0	0	-	19	18	3	9	0
	9	21	1	0	0	2	0	5	19	0	3	-	19	18	3	9	0
Med-conv	16	26	-	0	1	2	0	4	18	-	-	1	18	17	3	9	0
	15	35	1	0	0	2	0	4	16	0	0	-	16	15	2	8	0
	3	20	1	0	0	2	0	5	20	0	0	-	19	19	3	10	0
Large-conv	7	22	1	0	0	2	0	5	19	0	0	-	19	18	3	9	0
	6	24	1	0	0	2	0	5	19	0	0	-	18	18	3	9	0
	17	24	-	0	1	2	0	4	18	-	-	3	18	17	3	9	0
Average	-	22	1	0	0	2	0	5	19	0	1	0	19	18	3	9	0

Source: Author's calculations

S1: Cultivation; S2: Collection Centre; S3: Departure Port; S4: Port of Entry; S5: Ripening Facility; S6: Distribution Centre; S7: Retailer; S8: Consumer

T1: Farm to Collection Centre; T2: Collection Centre to Departure Port; T3: Farm to Port of Departure; T4: Sea Transportation; T5: Port Entry to Ripening Facility; T6: Ripening Facility to Distribution Centre; T7: Distribution Centre to Retailer; T8: Retailer to Consumer and the United Kingdom); Panama's bananas (Germany, the Netherlands and the United Kingdom); and Peru's bananas (the Netherlands). Primary data were also collected from the plantations, while secondary data and emission factors were derived from several databases.

- Lescot (2012) has compiled four case studies relating to three different plants: plant A corresponds to Luske (2010), while there is no information (except for the final destination of Europe) regarding plants B and C, due to confidentiality issues.

Figure 42 illustrates the results in relation to these references and, for comparative purposes, includes those derived from this study, where the contribution from the packaging activities at plantations have been separately presented, according to the other evaluations. Two values are presented in the Svanes (2012) analysis: the Svanes I column in Figure 42 represents the cradle-to-gate result, while the Svanes II column represents the cradle-to-grave figure. With regard to Eitner *et al*., an average of the four plantations (*Eitner I*) and an average for Ecuador (*Eitner II*) are included. The results in relation to the work of Letscot are included in Figure 42 and include the stages up to either the RDC (*Lescot BI*) or on arrival at the European harbour (*Lescot BII and C*).

The results from this study are lower than those reported by Svanes (2012) for the entire banana value chain (1.25 versus 1.77 tonne CO_2eq/tonne of bananas). The results for Ecuador from this study are also lower than those reported by Luske (2010) and Svanes (2012), which include all stages until the retailer stage (1.01 versus 1.12 and 1.37 tonne CO_2eq/tonne of bananas, respectively) or those results from the study by *Lescot* (2012) for the value chain up to the RDC stage (0.84 versus 0.93 tonne CO_2eq/tonne of bananas). The results from this study, however, are higher than the values reported by Eitner *et al*. (2012) for all stages up to the RDC stage (0.70 tonne CO_2eq/tonne and an average 0.65 tonne CO_2eq/tonne of bananas from Ecuador).

3.3 Detailed analysis of mayor contributors

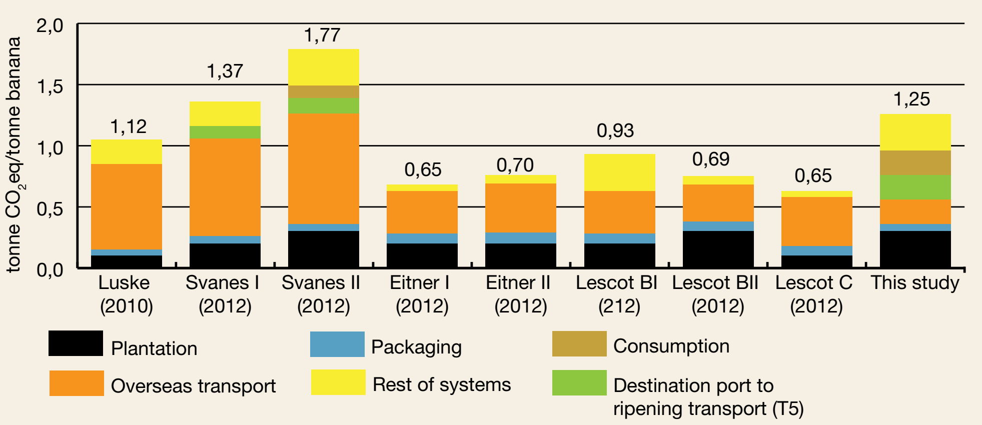
3.3.1 Banana cultivation on the farm

For further detailed information, Table 47 divides the carbon footprint associated with the farm into the activities involved in the cultivation of the banana and those associated with banana packaging, as in previous studies. It is evident that the results achieved in this study are in line with the figures of other authors.

The farms that were selected for this study were classified according to two criteria: size (small, medium and large) and production system (organic and conventional). No significant differences were found regarding the former, where the variability among farms within the same category can be even higher than the divergences between farms of a different size. A significant difference (24 percent), however, resulted between the average organic and average conventional banana (Figure 43).

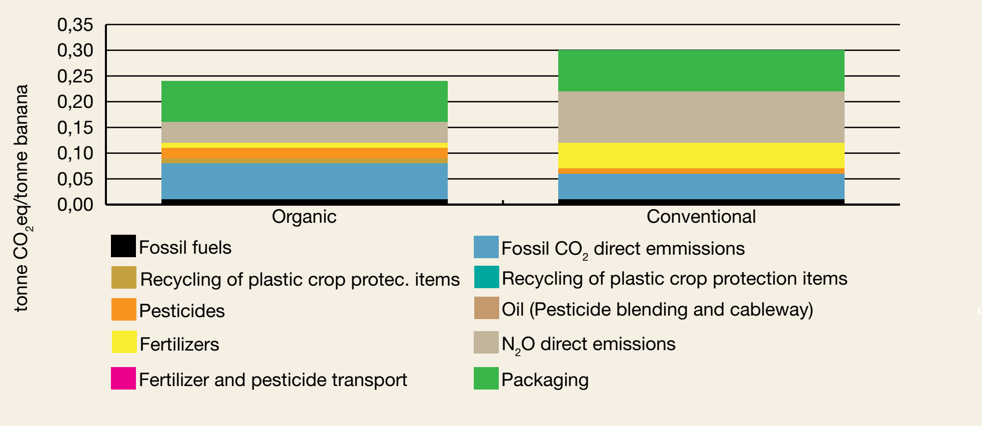
With regard to the cultivation activities of the banana, the main effects, in terms of global warming, are the CO_2 emissions that are associated with the

Figure 42 Carbon footprint results of banana value chains, reported by several authors



Source: Authors' calculations

Figure 43 Individual contributors to the average carbon footprint of Ecuador's organic and conventional bananas



Source: Authors' calculations

Table 47 Distribution between cultivation and packaging at banana farms

Farm	**Luske (2019)**	**Svanes (2012)**	**Eitner (2012) ORG**	**Eitner (2012) CONV**	**Lescot (2012) B I**	**Lescot (2012) B II**	**Lescot (2012) C**	**This study (2013) ORG**	**This study (2013) CONV**
Cultivation	0.14	0.22	0.11	0.35	0.27	0.29	0.19	0.17	0.23
Packaging	0.10	0.08	0.14	0.10	0.09	0.10	0.11	0.08	0.08
Total	0.24	0.30	0.25	0.45	0.36	0.39	0.30	0.25	0.31

Source: Authors' calculations

combustion of fuel (diesel and gasoline) that is used in pumps and agricultural machinery (terrestrial and aerial application of chemicals), the N_2O emissions from fertilized soils and the overseas production of fertilizers. The two latter items are more relevant to conventional plantations due to the amount and type of the fertilizers used. Furthermore, their N-content is higher than the N_2O emissions, which are also significant.

Svanes (2012) has identified the emissions - mainly methane (CH4)- that emanate from landfills of organic waste as one of the key issues (31 percent). In this study - and according to the information provided by the farmers - organic waste is left on the plantations, contributing to the fertilization of the soil. This, therefore, does not generate CH4, since anaerobic conditions do not take place. The other main contributors to GHG emissions that have been identified by Svanes (2012) are similar to those in this report. These are N_2O emissions (29 percent), fertilizer production (23 percent) and fossil fuel combustion (7 percent).

The Luske (2010) study indicated that N_2O emissions are very significant (47 percent), followed by fertilizer production (36 percent), crop protection manufactures (9 percent) and fuel combustion (7 percent). The same key components to GHG emissions were identified by Eitner *et al*. (2012), where fertilizer production was 27 percent, pesticide production was 22 percent, N_2O emissions were 26 percent and fuel combustion was 22 percent for the conventional farm. On the other hand, according to the same study, the organic method is dominated by N_2O emissions (54 percent) and CO_2 is emitted from the application of lime (26 percent).[42]

N_2O direct emissions are, therefore, a significant issue, making it compelling for this study to achieve the best estimation. The values obtained vary from 41 kg CO_2eq/tonne of organic bananas (62 kg according to Eitner *et al*. (2012)) to 100 kg CO_2eq/tonne of conventional bananas (91 kg according to Eitner *et al*. 2012), representing an average value of to 71 kg CO_2eq/tonne of bananas. This figure is slightly higher than the values reported by Luske (2010) (65 kg CO_2eq/tonne) and Svanes (2012) (62 kg CO_2eq/tonne), but these authors applied the default emission factors reported by the IPCC (IPCC, 2007), which are suitable for a mild climate. The factors applied in this analysis have been modified for a tropical climate and the particular types of soil that exist in the area.

With regard to banana packaging, cardboard is the main component, contributing to 82 percent of emissions - slightly lower than the value reported by Luske (2010) (84 percent) and Svanes (2012) (89 percent). Note that in this study the manufacturing of the cardboard boxes has been modeled on the basis of data provided by a local producer, resulting in a contribution in absolute terms of 66 kg CO_2eq/tonne of bananas, which is lower than all the values reported in the other studies: 67 kg CO_2eq/tonne of bananas (Svanes, 2012), 87 kg CO_2eq/tonne of bananas (Luske, 2010), 94 kg CO_2eq /tonne of bananas

---

[42] Note that in this study, CO_2 emissions from the application of lime were not included, as this compound was only used in 6 of the 17 farms inventoried. These were at a lower dose in comparison with nitrogen fertilizers.

(Eitner *et al*., 2012) and 100 kg CO_2eq/tonne of banana (Lescot, 2012), where values were directly taken from databases without being modified for national conditions.

3.3.2 Consumption

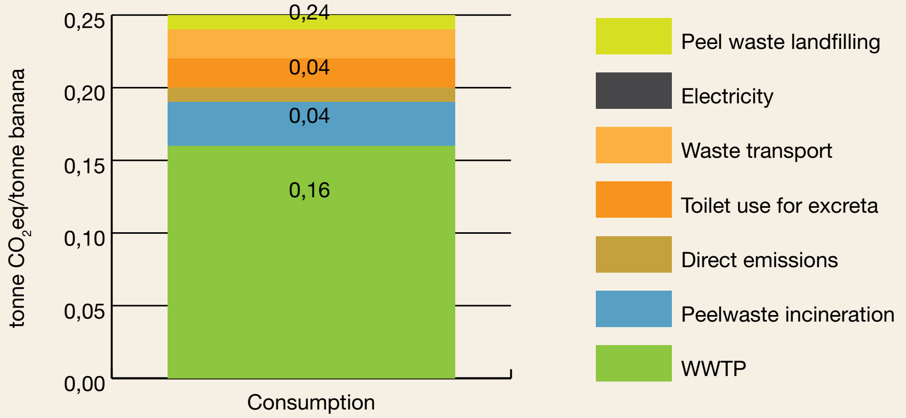
The significant contribution to GHG gas emissions relating to the consumption of the banana has not been included in previous studies, except in the case of Svanes (2012), where it is indicated as not significant (6.5 percent; Svanes II in Figure 42).

In this study, the landfill of the banana peel (Figure 44) is a key component of GHG emissions, at 66 percent of total carbon footprint. In absolute terms, this represents 0.16 tonne CO_2eq/tonne of bananas, much higher than the value reported by Svanes (2012) relating to Norwegian conditions (0.034 tonne CO_2eq/tonne of bananas). Another key GHG emissions component is the production of toilet paper, used upon human excretion of the banana after ingestion (6.65 kg CO_2eq/kg, which is rather high). This value, however, should be taken lightly in view of the fact that the data was not included in the EcoInvent database and was extracted from a different and dated database.

The significance of waste generation is reflected by the relevance of waste management and the contribution of consumption to the entire value chain. For more evidence, Figure 45 illustrates the different amounts of waste that is generated along the banana value chain. It shows that one tonne of fruit in the hands of the consumer generates 1.07 tonne of waste (upstream) and 0.4 tonne (downstream), totalling 1.47 tonne.

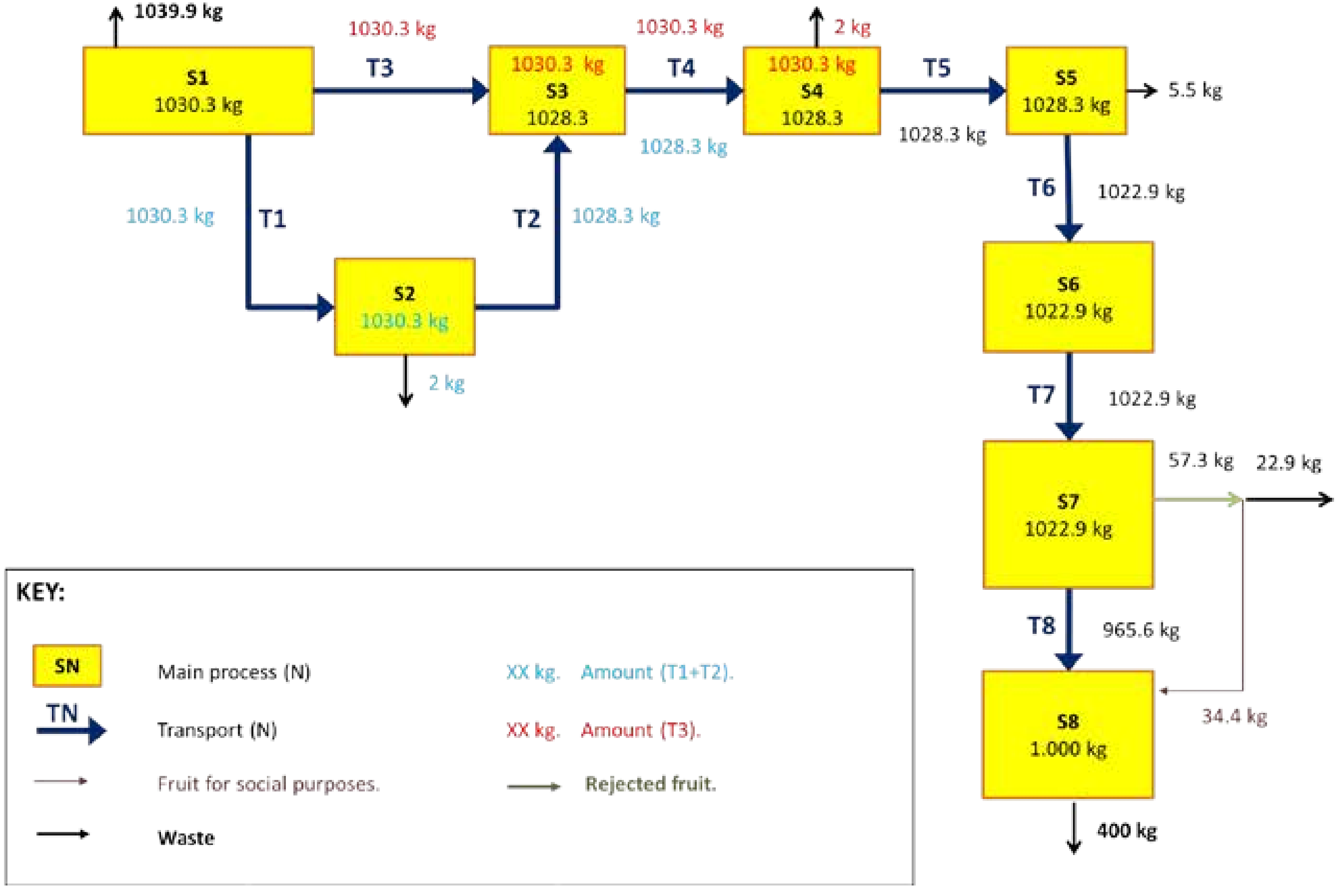
Svanes (2012) indicated the significance of waste generation along the value chain, although the main sources varied. His study reflects a loss of up to 26.3 percent at the retailer stage, whereas this study only reflects a loss of 2.24 percent

Figure 44 Distribution of the various elements considered at stage the consumption stage



Source: Authors' calculations

Figure 45 Waste streams generated along the banana value chain



Source: Authors' calculations

during transportation from the RDC to the retailer. This is based on national statistics and alternative methods to recover food that are in practice today.

3.3.3 Transportation by sea

The contribution to the banana carbon footprint by sea transportation represents 0.23 tonne CO_2eq/tonne of bananas, which is significantly lower than the results reported by Luske (2010) (0.70) and Svanes (2012) (0.75). It is in line, however, with those reported by Eitner *et al*. (2012) (0.21) and Lescot (0.26 for BI, 0.23 for BII and 0.29 for C).

The reason for this decrease is that a larger size of vessel is considered in this study (40 000 tonnes versus 15 000 tonnes (deadweight tonnage), in which case the fuel usage per unit of banana transported is lower. The decrease is also due to the fact that the return trip is partly (20 percent) used for transporting other goods, as reported by the shipping companies that were interviewed (other studies assumed the return of an empty vessel, due to lack of information). Furthermore, the assumption that the vessel capacity is used efficiently (100 percent, according to the information provided by the shipping companies) varies from the report by Luske (2010) (70 percent).

3.3.4 Transportation from port of entry to ripening facility

The reason for the high contribution of emissions relating to transportation from the port of entry is due to the consumption stage which takes place in Spain. The fruit still needs to be transported long distances after it has been unloaded in Rotterdam.

4. Conclusions

This evaluation has calculated the carbon footprint associated with the production of the banana in Ecuador and its ultimate consumption in Spain. It covers the entire banana value chain, with special emphasis on the activities of fruit cultivation and packaging that take place on the banana plantation.

Six types of farms were selected, based on size and production system. Significant differences in the amount of GHG emissions were evidenced between organic (0.25 tonne CO_2eq/tonne of bananas) and conventional plantations (0.31 tonne CO_2eq/tonne of bananas).

The carbon footprint of the entire value chain of Ecuador's banana, consumed in Spain, is 1.25 tonne CO_2eq/tonne of bananas (or 0.84 tonne CO_2eq/tonne of bananas if consumption is excluded, with the value chain ending at the stage of RDC). The stages within the value chain that contribute the most GHG emissions to global warming are Plantation (22.1 percent, average), Consumption (19.2 percent, average), Sea Transport (18.7 percent, average) and Transportation from the port of entry to the ripening facility (18.0 percent, average).

Taking into account the previous studies that have been undertaken with regard to the carbon footprint of the banana and the uncertainties and weakness that have been identified, special effort has been made in this evaluation to refine the calculation of N_2O direct emissions at the plantation and maritime transportation levels. The values in this study are lower or are in line with those available in the literature, but their calculation is considered more tailored to the characteristics of Ecuador's banana production.

©FAO/Aziz Elbehri

CHAPTER 6:

CLIMATE CHANGE POLICIES AND THEIR POTENTIAL IMPACT ON ECUADOR’S BANANA SECTOR – AN ECONOMIC ANALYSIS

David Skully[*]

---

[*] FAO consultant

1. Introduction

This chapter examines how the adoption of climate change policies will likely influence the banana sector in Ecuador. While the direct and indirect effects of climate change policies on the demand for bananas and on the international banana supply chain are still unknown, there are an unlimited number of possible policy combinations that can be considered. This chapter, therefore, poses the question of how the supply and distribution of bananas could change if the world were to adopt a fixed GHG emission tax. While it may be purely hypothetical, since this is unlikely to occur, it is nevertheless evident that more and more countries are adopting some in-depth and broader policies to reduce GHG emissions. This analysis will provide information on the direction this change could take, while distinguishing between the important and relatively unimportant aspects.

The global GHG mitigation policy that is assumed in this analysis is a single world-wide tax on all GHG emissions, applied as broadly and as upstream as possible. It assumes that most of the revenue is refunded to households and businesses, so that incomes and revenues, respectively, do not decline on average because of an emission tax. These hypotheses will provide a starting point to the debate on the extent to which the production and distribution of bananas could change if broader policies to reduce GHG emissions were in place.

The study begins with the value that such a tax could have on the banana industry, particularly in Ecuador, based on estimates of the social cost of CO_2 (Section 2). It then examines how an emission tax would alter the demand for bananas in the markets of developed countries (Section 2.1). Finally, an examination is made of the banana supply chain for points where GHG emission abatement may occur and the potential for structural change in terms of the logistics of the banana sector. This is done by reviewing transportation and distribution methods (Section 4) along the supply chain and, subsequently, the growing of bananas (Section 5) and the policies to reduce on-farm emissions.

2. The social cost of carbon dioxide

The ideal tax rate on emissions should come close to the marginal benefit of reducing the GHG emissions. This can be approximated by the social cost of CO_2 (SSC), for which there is a range of estimates. The SSC is the long-term cost to the world economy of an additional unit of CO_2 emissions. The carbon tax that is currently applied or proposed is approximately USD 30 per tonne of CO_2e. The Province of British Columbia, Canada, charges Can$ 30 per tonne of CO_2e emissions for all types of fuel (Ministry of Finance, 2013); the EU proposes to harmonize Member States' fuel tax rates to at least €20 per tonne of CO_2 emissions (European Commission, 2013); and the United States Congress has drafted a legislation for a charge of between USD 25 and USD 35 per tonne of CO_2e emissions (United States House of Representatives, 2013; and Fieldhouse and Theiss, 2013).[43]

---

[43] For carbon prices in other national and subnational schemes, see Kossoy *et al*. (2013).

In May, 2013, the United States Government issued revised SSC estimates. Table 48 indicates that these estimates will increase at five-year intervals until 2050. Columns 2, 3 and 4 differ because of the discount rate that is used to calculate the long-term costs.[44] The lower the discount rate, the less rapid the future discount will be; therefore, it is assumed that the SCC will be at its lowest level for the 5 percent discount rate and at its highest level for the 2.5 percent discount rate. Some experts will contend that the future should not be discounted in SCC estimates, since it will discriminate against future generations. A discount rate of zero, however, will result in significantly higher SCC values. Discount rates between 2 percent and 3 percent are generally accepted, since they represent a range of long-term real interest rates. Column 5 in the table - unlike the others - is based on the 95th percentile of the distribution of SCC estimates, while those in columns 2, 3 and 4 are based on the average of the distribution. To incorporate some of the increased fat-tail risks of climate change, a value is applied from the upper end of the distribution (Pindyck, 2013).

2.1 The demand for bananas

From various life-cycle analyses (LCAs) of the carbon footprint of bananas - exported from Central America and sold in EU and United States supermarkets - there is approximately 1 kg-CO$_2$e/kg of bananas (Table 51), later discussed. To assess the impact of a broadly applied emission tax on the consumer demand for bananas, consideration should be given to how the emission tax is applied to other goods and services, since the relative tax rate will influence consumer demand. Figure 46 illustrates the GHG emissions per kilo of various food items at the retail

Table 48 Revised social cost of CO$_2$, 2010-50
(in 2007 US dollars per metric tonne of CO$_2$)

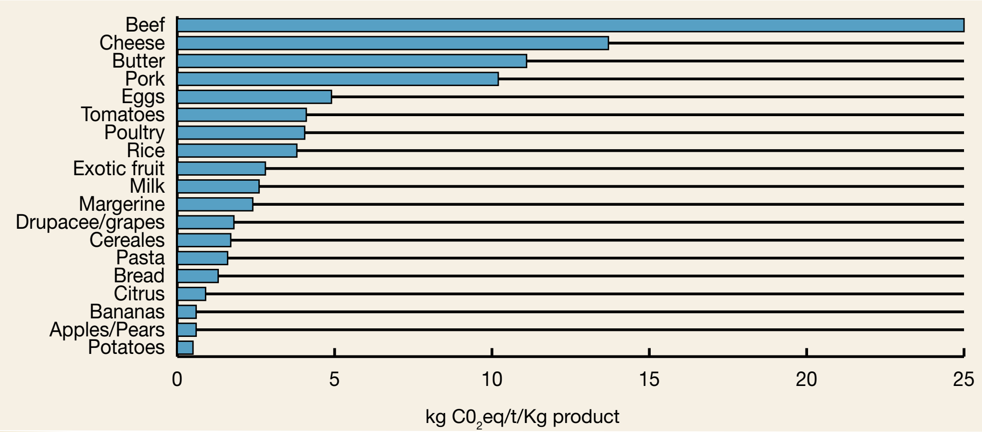
Discount Rate	**5.0%**	**3.0%**	**2.5%**	**3.0%**
Basis:	**Avg.**	**Avg.**	**Avg.**	**95th**
2010	11	33	52	90
2015	12	38	58	109
2020	12	43	65	129
2025	14	48	70	144
2030	16	52	76	159
2035	19	57	81	176
2040	21	62	87	192
2045	24	66	92	206
2050	27	71	98	221

Source: Interagency Working Group on Social Cost of Carbon, United States Government (2013)

---

[44] Dividing 70 by the discount rate shows how much future costs are discounted, relative to current costs. For example, a discount rate of 5 percent value costs 14 years in the future at half the value of current costs (70/5 = 14); the same discount rate value costs 28 years in the future at one quarter of current costs; and so forth, every 14 years, the value is halved.

Figure 46 GHG emissions of selected food items (per kilo)



Source: Adapted from Berners-Lee and Hoolohan (2012)

level. Bananas are at the lower end of emissions per kilo, with approximately 1 kg of CO_2e/kg. Berners-Lee (2010) wished to address the erroneous but, nevertheless, common assumption that imported produce leaves a significant carbon footprint. This may be so, but it is not in the case of the banana. This underscores the value of conveying information to consumers with regard to GHG emissions.[45]

Figure 47 ranks the same set of food products in terms of kilos of CO_2e per US dollar of retail purchase. Bananas represent approximately one kg CO_2e/USD, ranking slightly higher by way of this measure than by way of emissions per kilo. This is due to their being relatively inexpensive per kilo, compared to citrus, stone fruit, grapes or exotic fruits.

In terms of the entire range of food products, bananas would represent a tax rate that is much lower than the average. For instance, the tax rate for most animal products is at least three times higher than for bananas. An emission tax would, therefore, encourage consumers to shift away from relatively high-taxed beef, pork and dairy products and lead them to favour cereals, fruits, roots and tubers, which have a lower tax rate.

With regard to all categories of consumer expenditures (Table 49), the average dollar in the United States of household expenditure has a carbon footprint of 1.4 kg to CO_2e (Grainger and Kolstad, 2010).[46] The average United States

---

[45] Both figures (per kg; per USD) are adapted from Berners-Lee and Hoolohan (2012). Weber and Matthews (2008) provide a similar analysis for food categories in the United States. Edwards-Jones *et al*. (2008) examine, empirically, whether local food is best; Brenton *et al*. (2009) explore the threat of carbon labelling to exports from less developed countries.

[46] Grainger and Kolstad (2010) used expenditure data from the 2003 United States Consumer Expenditure Survey. This study is used in this analysis, since it examines most major GHG emissions, while many studies examine only CO_2 emissions. For agricultural products, CO_2 greatly understates GHG emissions owing to the use of fertilizers and the N_2O and methane that are emitted by livestock. With regard to livestock and emissions, see FAO (2013).

Figure 47 GHG emissions of selected food items (per U.S. dollar)

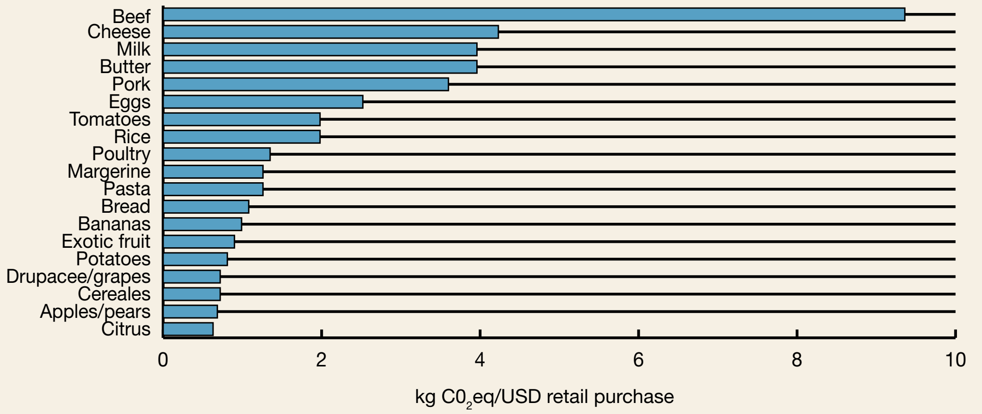


Table 49 CO_2e footprint per dollar of spending, relating to the middle quintile of United States households (by expenditure category)

	Kg CO_2eq /USD	**Share of expenditure**	**Share of emissions**
		%	
Fuel oil and other fuels	12.7	0.3	2.3
Electricity	12.3	2.5	21.6
Gasoline and motor oil	10.9	3.3	25.6
Natural gas	9.4	0.8	5.5
Water and Public Services	6.5	0.8	3.7
Food and alcohol	1.7	12.6	14.8
Total Expenditures	**1.4**	**100.0**	**100.0**
Other expenditures	0.6	11.5	5.3
Shelter	0.5	38.3	13.8
Apparel, furnishings,supplies, etc.	0.5	7.9	2.6
Transport and vehicle expenses	0.4	13.7	3.6
Healthcare	0.2	5.9	1.0
Telephone services	0.1	2.3	0.2

Source: Calculated from data in Grainger and Kolstad (2010) footprint per dollar is similar to that of Canada, while the average in the EU is approximately three quarters and in Japan, it is approximately half of the United States level (Hertwich and Peters (2009).[47]

Table 50 shows, in the first column, the estimates of GHG emissions per average dollar of household expenditures in Japan, the United States and the EU. These three markets account for over two thirds of global banana imports. The second column indicates the effective emission tax rate for an average dollar of expenditure for a USD 30 per tonne of CO_2e emission tax. In the case of the United States, a tax that is 3.0 cents per kilo x 1.4 kilos = 4.2 cents per dollar of expenditure, resulting in a tax rate of 4.20 percent. Columns 3, 4 and 5 represent the calculation of the emission tax rate for bananas. (The most recent United States retail price of the banana is USD 1.35 per kilo.)

In terms of Ecuador's bananas, the carbon footprint is 1.2 kg-CO_2e per kilo, calculated to 0.89 kg-$C0_2$e per dollar of retail bananas and resulting in a tax rate of 2.67 percent. The last column indicates how the USD 30 emission tax can change the price of bananas, relative to all household expenditure. In the three markets, the relative retail price of bananas drops.

In developed market economies, the demand for bananas is relatively insensitive to price change; the price elasticity of demand is estimated to be approximately -0.4. To simplify the analysis, the assumption is that the value is higher, whereby an elasticity of -0.50 would imply that the quantity in demand decreases by 0.5 percent for every 1 percent increase in price. The relative price decreases in Table 50 indicate that a USD 30 carbon emission tax would increase the demand for bananas by approximately 0.75 percent in North America, 0.68 percent in the EU and 0.26 percent in Japan. The effect is significantly nominal, despite a deliberate overestimation. In other words, the net effect of a USD 30-USD 50 emission tax on the retail demand for bananas would be hard to distinguish from the usual month-to-month variation of prices and sales, despite the usual fluctuations in energy prices, exchange rates and business cycles that influence commodity trading. A global, broad-based emission tax of USD 30, therefore, will likely have little impact on the demand for bananas; it would, instead, slightly increase demand.

Caution should be made when taking into account the estimates derived above, which were based on aggregate data from diverse sources and on various assumptions. First, the conclusion above that little impact on the demand for bananas is likely to take place is dependent on the assumption of a broad, world-wide emission tax. Under the Kyoto Protocol, developing countries are less committed to reduce emissions (including exemptions, such as in the case of international shipping) than are developed countries. The emission tax on bananas for retail sale, therefore, would only apply to those emissions within the borders of developed countries, primarily through upstream fuel and energy levies. As such, imported bananas will

---

[47] Compared to North America, Japan and the EU are more densely populated, housing units are smaller, and energy prices are higher. Druckman *et al*. (2011) report a similar pattern of carbon footprint per expenditure category for the United Kingdom. Countries can differ in how expenditures are categorized and measured, and Tukker & Jansen (2006) offer a comparative review of household carbon footprints.

Table 50 Change in the relative price of bananas due to a USD30/tCO_2e emission tax

	Total expenditure kg-CO_2e/USD	Average emission tax rate	Banana retail price USD/kg	Bananas kg-CO_2e/USD	Banana emission tax rate	Change in relative banana price*
	....%					
United States	1.40	4.20	1.35	0.89	2.67	-1.47
European Union	0.98	2.94	2.35	0.51	1.53	-1.37
Japan	0.70	2.10	2.30	0.52	1.57	-0.52

Source: Retail price data from FAO: Prices for France and the United States relate to March 2013; those for Japan relate to December 2012

* The last column divides the banana tax rate by the average tax rate and subtracts one (tax on bananas/tax on all goods)

be subject only to a portion of the full levy that has been assumed in the analysis, resulting in a price drop beyond what has been calculated (Table 50). This would lead to a larger percentage increase in the demand for the fruit.

Second, if some products or sectors are taxed at a lower rate - or are exempt from an emission tax - the relative price effects assumed above would need to be modified. The dairy sector in virtually all developed countries, for example, benefits from significant producer support. Should the dairy sector be provided its usual preferential treatment, the tax on emissions would reduce the price increase that is assumed above and consumers, therefore, would have less incentive to reduce their consumption of dairy products and switch to lower-taxed foods.

Third, the analysis assumes that the emission tax is fully refunded so that aggregate household income is unchanged. However, because households differ in energy consumption, rebates to individual households will generally not equal the tax paid, resulting in a net aggregate income effect.

Fourth, the calculations in Table 50 relate only to changes in demand: the analysis does not take into consideration the supply response to an emission tax. Should humans reduce their consumption of animal products, the question that arises is how should the pasture and grazing land - as well as the arable land - that was used to produce the feed and fodder in relation to the animal products be reused? Changes on the supply side will alter relative prices and contribute to a change in demand.

3. Post-purchase emissions

The LCA of food items ends at the point of sale to the consumer, while other LCAs include the transportation from the point of sale to the home, as well as household storage, preparation, waste and disposal. In the case of the banana, it is usually eaten raw and is usually stored at room temperature to facilitate ripening, thus requiring minimal energy. Transport from retail store to the home, on the other hand, is the principle post-purchase contributor to the carbon footprint of the banana. Jones and Kammen (2011) examine GHG abatement opportunities for United States households, where the results vary according to household income, size, composition and location. A common pattern, however, emerges, where a change in transportation habits would be the greatest contribution to the abatement of emissions. This specifically refers to a reduction in air travel, a shift towards more energy-efficient vehicles, less distance driven and an increase in the use of mass transit. A change in food consumption (less meat and dairy products) and in household energy use (less heating and cooling systems; use of efficient light bulbs; smaller refrigerators; and line-dry laundry in lieu of electric dryers) will offer similar opportunities for abating GHG emissions.

An emission tax on the price of fuel and energy could contribute to a shift in shopping patterns - shopping closer to home or less frequently - while increasing the average amount of grocery purchases, particularly in terms of suburban and rural households. Consumers usually buy ripe or almost ripe bananas, although they regularly purchase produce that requires a few days to ripen (e.g. tomatoes, avocados and other climacteric fruit). In the case of the banana, the patience of the consumer could be cultivated. To remind consumers that bananas are greener than normal could be effective, as would a price discount for greener bananas compared to ready-to-eat yellow bananas.[48]

4. The supply chain from farm to retail

This section is empirically based on three recent banana LCAs that have been undertaken. One relates to Ecuador's banana sector and the bananas that are shipped to Spain via Rotterdam, the Netherlands (see Chapter 4). The second relates to Dole bananas that are exported from Costa Rica to Northern Europe (Kilian, *et al*., 2012); and the third refers to Chiquita Brand International, Inc. (CBI) bananas that are sent from Central America to the United States (Craig *et al*., 2012). The CBI study refers to the weighted average carbon footprint of bananas from several production areas in Central America to several ports in the United States and then to retail locations across the country. Table 51 compares and summarizes the results of the three LCAs relating to the supply chain. The carbon footprint is expressed as the CO_2-equivalent in kilos per tonne of bananas for each segment of the supply chain (kg-CO_2e/t), equivalent to grams of CO_2e per kilo of bananas.

The carbon footprint calculations are similar (1 010 kg, 900 kg and 1 077 kg) but their compositions differ markedly, especially in terms of distance. Ocean transportation accounts for three quarters of the carbon footprint relating to bananas shipped to Northern Europe, but approximately one fifth for those exported to the less distant American market. Since the United States is less densely populated than Japan and Northern Europe, its ground transportation costs are ten times greater than those in Northern Europe. The wholesale, retail and ripening facilities of the United States are also more energy-intensive than European facilities. Similarly, ground transportation from Rotterdam to the

---

[48] Consumers respond to prices by adjusting the quantity of their purchases and home inventories (Hendel and Nevo (2006) and McKenzie and Schargrodsky (2011)).

Table 51 CO_2 equivalent footprint of bananas at retail ($kgCO_2e/t$)

	Ecuador to Spain	**CBI: Central America to United States**	**Dole: Costa Rica to EU**
On the farm	280	276	141
Domestic transport	20	44	16
Marine transport	240	198	789
Foreign ground transport	380	216	40
Ripener	30	28	0
Wholesale/retail	60	138	84
Total	**1 010**	**900**	**1 070**

Sources: Ecuador-Spain: Ecuador's bananas delivered to retailers in Spain via Rotterdam, the Netherlands (see Chapter 4); CBI-United States: bananas from Central America delivered to United States supermarkets (Craig *et al*., 2012); Dole-EU: bananas from Costa Rica delivered to supermarkets in Northern Europe (Kilian *et al*., 2012).

wholesale and retail locations in Spain is the largest contributor to the carbon footprint relating to bananas from Ecuador.

From the farm gate to retail sale, the banana's carbon footprint is generated by two components: energy for transportation and energy for refrigeration and ripening. A GHG emission tax has a relatively high effect on the tax rate on energy and its imposition would create a varying abatement reaction at each link in the supply chain. Marginal abatement costs would be necessary to forecast the abatement reaction. In the absence of such information, the general outline is evident: an emission tax would raise the return of more energy-efficient engines and condensers and would contribute to the adoption of new technologies. In addition, some operational norms would shift. It is not known, however, whether the marginal change in each link of the supply chain would result in a slightly more efficient form of the chain or whether there would be sweeping changes in the supply chain itself.

Logistics systems can react structurally to minor changes. McKinnon (2008) argues that higher emission taxes, together with road and congestion charges, increase the cost of backhauling and loads that are less than full. Ballot and Fontane (2010) examined the horizontal pooling of truck and rail operations by rival French retail chains and discovered that the carbon footprint could be reduced by 25 percent, with most of the gain resulting from reduced cross-hauling, backhauling and fuller loads. Notteboom and Rodrigue (2008, 2009) discuss how emission charges and congestion costs are transforming the geography of container ports and inland distribution networks.

The relatively brief storage life (maximum of 28 days) of the banana dictates the structure of the banana supply chain. Bananas are perishable inventory, according to logistics specialists, whereby the flow of deliveries must closely match the flow of sales to prevent excess waste or loss in sales (Nahmias, 2011; and Goyal and Giri, 2001). Since a high penalty is imposed in the event of delays, extending the storage life of the banana would reduce the time constraint and would likely contribute to a major structural change in the supply chain and lessen the carbon footprint. There may be other areas for change in addition to the extension of storage life.[49]

4.1 Transportation by sea

Ocean shipping is a leading source of GHG emissions in relation to imported bananas. The Kyoto Protocol explicitly excludes international air and maritime transportation from national emission targets, which are under the purview of the International Civil Aviation Organization and the International Maritime Organization (IMO), respectively. Attention has recently focused on civil aviation emissions due to EU efforts to request flights in and out of EU Member States to submit emission permits in an attempt to impose a unilateral adjustment to border taxes. The opposition from countries outside of the EU, however, has halted the EU's unilateral efforts and has shifted the locus for negotiation from Brussels to the International Civil Aviation Organization as a more appropriate multilateral forum.

The IMO is the international forum for GHG mitigation relating to maritime transportation. Bodansky (2011) notes that the IMO is unusual among organizations under the United Nations, since it requires a qualified majority of votes, whereas most other organizations are based on consensus, which allows an individual member to veto or delay negotiation. The IMO's instrument for environmental regulation is MARPOL, the International Convention for the Prevention of Pollution from Ships, which has been in force since 1973 and has been subsequently amended various times. The fact that voting now takes place with a qualified majority facilitates the decision-making of the IMO. In 2011, for example, the IMO adopted mandatory emission standards for new ships by a 49 to 5 vote, with Brazil, Chile, China, Kuwait and Saudi Arabia in opposition (IMO, 2011).[50] This indicates that the IMO can arrive at a consensus on an emission tax for maritime transport ahead of the adoption of similar broad GHG abatement measures by other international conventions, such as the United Nations Framework Convention on Climate Change and the Montreal and Kyoto Protocols. Given that major banana import markets already impose substantial energy levies, the control of emissions relating to maritime shipping could result in the most significant climate policy outcome that the banana supply chain would be confronted with, given the reliance on maritime transportation.

The energy efficiency relating to maritime shipping is expressed in grams of CO_2 equivalents per tonne-km of product shipped. Table 52 indicates the carbon footprint per tonne-km for bananas, calculated from data in the three LCA studies relating to key shipping routes. These values are higher than those for other

---

[49] There are technological innovations that can increase the storage life of the banana by slowing the ripening process (ACS, 2012). It is not known, however, whether these innovations can be scaled up to become commercially viable.

[50] The IMO has also expanded MARPOL Annex VI (Regulations for the Prevention of Air Pollution from Ships), to reduce the GHG emission of sulfur oxides (SOx) and nitrogen oxides (NOx). There is, however, no agreement to date regarding CO_2.

Table 52 Carbon footprints for maritime transportation of bananas

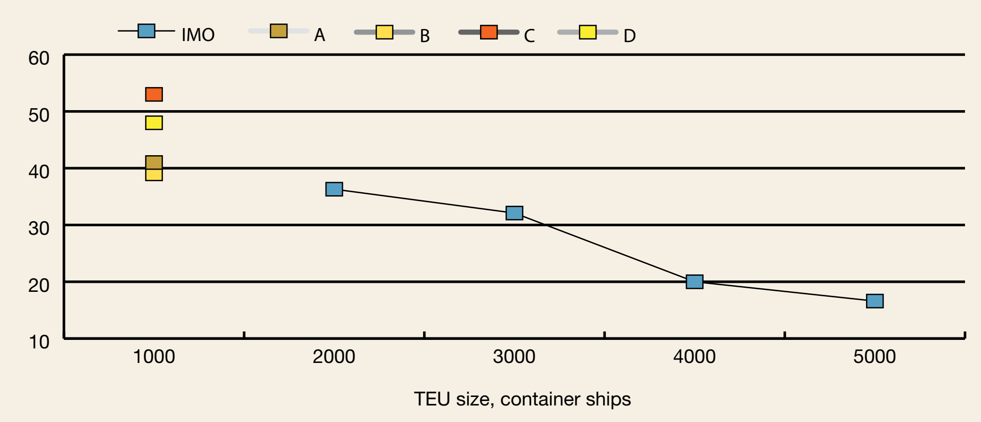
Route	**g-/CO_2t-km**
A: Puerto Quetzal GT to Port Hueneme, United States	95
B: Puerto Cortes HN to Gulfport, United States	86
C: Puerto Limón CR to Antwerp, Belgium	69
D: Ecuador to Rotterdam, the Netherlands	41

Source: Routes A and B: (Craig *et al*., 2012); Route C: (Kilian *et al*., 2012); Route D: (see Chapter 4); a backhaul factor of 1.8 has been applied to Route D to make it consistent with the other measures.

methods of maritime transportation; in fact, they exceed the emission rates of rail cargo.[51]

An IMO survey of the GHG emission efficiency of all classes of international shipping reports that general cargo ships range between 11 and 20 g-CO_2/t-k; larger ships are more energy efficient; refrigerated cargo ships, 13 g-CO_2/t-km; and containerships range from 13 to 36 g-CO_2/t-km. The highest value relates to the smallest class of containership (less than 1 000 TEU).[52] Figure 48 plots the GHG efficiency values for container ships by TEU size from the IMO survey and the values are calculated from the data in the LCAs. Three shipments from Table 52 have been plotted, based on a 400-TEU size ship (Buhaug *et al*.,

Figure 48 Maritime Shipping: GHG scale of efficiency



Source: IMO (Buhaug *et al*., 2009); shipping routes from Table 5

---

[51] The calculations apply a backhaul factor of 0.80. Weber and Matthews (2008) have surveyed emission atesfor major transportation modes.

[52] TEU: 20-foot equivalent unit.

2009:131, Table 9.1). Note that the IMO study only includes CO_2 emissions, while the LCAs indicate CO_2e values. The LCA study, undertaken by CBI, explains the high emission rates for bananas:

According to Craig *et al*. (2012:8),

> *"Bananas are brought to market in specific vessels that are smaller than the normal large container ships used for transoceanic freight. The higher emissions of CBI's ocean operations are attributable to a number of factors, including smaller vessels, lower utilization on the backhaul, and higher sailing speeds. Cargo on the backhaul portion of the voyage represents only 22 percent of total tonnes shipped, and can be as low as 7 percent for certain rotations."*

Banana ships sail faster than normal container ships, since the bananas are more perishable than most cargo. The smaller size of these ships relates to the steady flow of bananas, from harvest to consumption - as well as the capacity of ripening centres.[53] There are obvious scales of efficiency in ocean shipping. A shift to a 2 500-TEU container ship would reduce emissions by over 40 percent. The total volume of banana shipments to major markets (Japan, North America and Northern Europe) would justify the use of larger vessels, but this capacity would require current rival shipping firms to coordinate or pool their shipments.[54] The gains from horizontal supply chain pooling banana would fall short of those gains reported by Ballot and Fontane (2010) relating to retailers in France. Since a cargo imbalance would be much greater for banana shipping routes, it would be necessary to reposition the refrigerated containers at banana export points. Larger ships would require even greater backward vertical coordination with producers and forward vertical coordination with distributors and major retail chains. The capacity for handling to facilitate larger shipments also may need to be expanded.

4.2 Domestic transportation

GHG emissions from farm to port in Ecuador are due, almost entirely, to transportation and the use of petroleum-based fuels. From a study by Hospido and Roibás (Chapter 4), Figure 49 plots the carbon footprint of the domestic transportation of bananas from a range of producers in Ecuador. The average carbon footprint is 20 kg-CO_2e per tonne. Some banana producers pass through an intermediate depot, others ship directly to port. Emissions increase with distance, ranging from 10 to 60 kg-CO_2e per tonne.

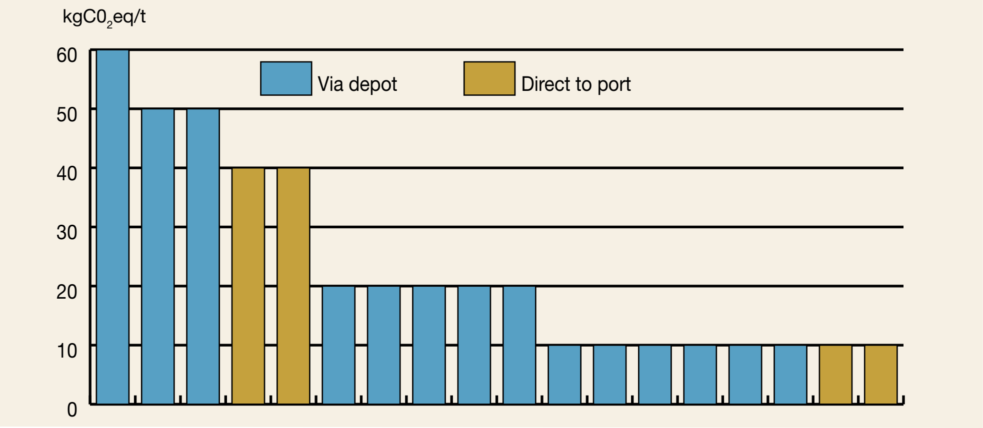
An emission tax - based on USD 30 per tonne of CO_2e - on petroleum fuels would be approximately 7 cents per litre; the precise value would depend on the

---

[53] A large amount of literature exists relating to research on maritime GHG abatement. A recent survey was undertaken by Psaraftis and Kontovas (2013).

[54] A study of banana maritime transportation along the lines of Ballot and Fontane (2010) would be worthwhile. Rodrigue *et al*. (2013) have presented a good review of transport issues with regard to bananas.

Figure 49 Carbon footprint relating to domestic transportation



Source: Hospido and Roibás, Chapter 4

average carbon content of the fuel and assumptions on the average combustion efficiency. The different grades of gasoline are taxed at approximately 6.7 cents per litre, while diesel is taxed at approximately 7.7 cents per litre. The most recent pump price in Ecuador is 58 cents per liter; thus, a 7-cent per litre tax would have an effective emission tax rate of approximately 12 percent.55 The impact of such an increase on the cost of fuel - after some short-term adjustments - would contribute to greater efficiencies in the logistics of domestic transportation. As noted earlier in this chapter, fuel prices and road charges would incentivize pooling supply chains to reduce backhaul and would minimize the proportion of loads that are less than full.

Greater GHG emission reductions are likely in the longer term from adjustments to infrastructure. The increased risk of flooding and the likely need to invest in water management systems - discussed in Chapter 2 - could result in some shift in the production of bananas. This may also apply in the case of investing in road systems. With regard to the planning process, the application of a shadow price for fuel, including an emission tax, may generate a proportion of the reduction in GHG emissions that is appropriate, without having to impose a fuel tax.

5. Policies to control on-farm emissions at the national level

A recent LCA of Ecuador's banana production (see Chapter 4) provides the empirical basis for the discussion of on-farm emissions. Table 53 indicates the

---

[55] Average annual price for 2012 (World Development Indicators series EP.PMP.SGAS.CD). Ecuador's petrol prices in 2012 were approximately 30 percent below notional world petrol prices, while Mexico's was USD 0.86/l. It is, therefore, difficult to calculate an effective emission tax rate with the subsidy.

Table 53 CO_2 equivalent footprint of (on-farm) Ecuadoran banana production, $kgCO_2e/t$

	Conventional	Organic
N_20 Direct Emissions	100	41
Fertilizer Nitrogen-based	46	12
Packaging	81	80
Fossil-fuel related	63	97
Other Farm Chemicals	13	13
Other	7	5
Total	**310**	**248**

Source: Hospido and Roibás, Chapter 4

average GHG emissions for conventional and organic banana producers who were surveyed.[56] On-farm emissions account for approximately 30 percent and 25 percent of the carbon footprint, respectively, of conventionally and organically grown bananas in Ecuador, which are exported for retail sale in Spain.

For conventional producers, who account for most of Ecuador's exports, almost half of on-farm emissions derive from the use of nitrogenous fertilizer or from the direct emission of nitrous oxide (N_2O) – 146 kg/t in total. A gram of nitrous oxide has 310 times the global warming potential as does a gram of CO_2. Thus, a minor improvement in the efficiency of fertilizer use would result in a greater reduction of GHG emissions, compared to other plausible banana-related abatement efforts within the scope of Ecuador's policy-making. The effects of a possible tax on nitrogen-based fertilizers are examined below.

5.1 Packaging

Packaging (81 kg/t) is the second largest contributor of GHG emissions in relation to imported bananas, accounting for approximately one quarter of the on-farm carbon footprint of conventional producers and approximately one third of the carbon footprint of organic producers. Conventional and organic producers use approximately the same amount of packaging from an emission perspective, since the boxes for containerized transportation and handling are standardized. To reduce the emissions related to packaging would be difficult for Ecuador to do unilaterally, since standardized packaging is what allows the supply chain from farm to retail to function seamlessly. Any innovation in packaging would need to function at all stages of the supply chain. While recycling and disposal of packaging material can take place independent of package design, the best stage to do this is at the point of sale or consumption in the destination countries.

---

[56] These averages are simple and are not weighted by the volume of production of the respective producers. The simple averages of the conventional and organic values in Table 53 correspond to the total values reported for Ecuador's on-farm GHG emissions in Table 54.

5.2 Emissions as a consequence of fossil-fuel

Emissions from fossil fuels (63 kg/t) account for approximately one fifth of GHG emissions with regard to conventionally produced bananas and one third from organically grown bananas. Most of these emissions derive from fossil fuels that are used for on-farm agricultural equipment and power generation. In economic terms, the data are similar to those that relate to domestic transportation, discussed in Section 4.2, where the addition of a petrol tax of 7 cents per litre would encourage some energy conservation and increase the return on more energy-efficient equipment. Fossil oils also are used as emulsifiers for pesticide blending and as lubricants. They emit CO_2 but at a slower rate than combustible hydrocarbons. Unless competitively-priced bio-emulsifiers or biolubricant substitutes are available, the demand for fossil oils for these uses is likely to be relatively price insensitive. A CO_2 emission tax, therefore, would have less impact on emissions than on the emissions from combustible hydrocarbons.

5.3 Fertilizer and nitrous oxide emissions

The greatest potential for reducing GHG emissions related to the production of bananas is to lower the nitrous oxide (N_2O) emissions from nitrogen-based fertilizers and improve soil management practices. A USD 30-per tonne CO_2e emission tax for nitrogenous fertilizer would equal USD 186 per tonne of nitrogen content.[57] Urea, the most widely traded form of nitrogenous fertilizer, is 46 percent nitrogen and, thus, it would be taxed at USD 85.56 per metric tonne. Since urea is currently quoted at approximately USD 350 per metric tonne, this would result in an effective emission tax rate of 24.4 percent, depending on the market price of urea. Were urea to trade at USD 200 per metric tonne, the tax rate would be 43 percent. Given that nitrogenous fertilizers are valued depending on their nitrogen content, the tax rate calculated for urea would more or less include all nitrogenous fertilizers. Due to the significant effects of N_2O on global warming, these emission tax rates are the highest tax rates that are discussed in this chapter.

According to FAOSTAT, Ecuador imports all of its synthetic fertilizers. The absence of a domestic fertilizer manufacturer would remove the potential for opposition to a fertilizer levy. Moreover, the administration of taxes is feasible when the levy is imposed at the border with minimum leakage. The higher cost of synthetic fertilizer would increase the price of domestic organic nitrogen, which would encourage banana producers to reduce either their use of fertilizer, use it more efficiently or combine both uses.[58] This would result in a significant lowering of the GHG emissions from production.[59]

---

[57] A tonne of nitrogen generates 20 kg of N_20 (using the generally assumed factor, 0.02). A kg of N_20 has a global warming potential of 310 kg of CO_2. Therefore, one metric tonne of nitrogen will generate 6.2 metric tonnes of CO_2e. At USD 30 per metric tonne of CO_2e, the tax would be USD 186 per metric tonne of nitrogen content.

[58] In microeconomic terms, this is a tax on a factor of production. Banana producers respond by moving along their (fixed) value of marginal product curve, thus purchasing less chemicals. Alternatively, they shift their VMP curve upwards, using chemicals more effectively or some combination thereof, reducing input and improving the efficiency of input use.

[59] The revenue from a tax on fertilizers could contribute to funding the research on the use of nitrogen, as

The imposition of a fertilizer levy, however, has some negative consequences. The yield and output of bananas would drop, contrary to the goal for "*No más hectáreas de banano sino más bananos por hectárea*" (Not more hectares of bananas, but more bananas per hectare). While it would be ideal to limit the tax on the excessive use of fertilizer, it is not administratively feasible.[60]

Another consequence of a fertilizer tax is that there is an extensive traditional agricultural sector in Ecuador, where fertilizer is underused. Higher fertilizer prices would further discourage the adoption and use of fertilizer in the traditional sector. The reduction in household welfare and nutrition could outweigh the benefits of lower GHG emissions by traditional-sector households.

The N_2O emissions that are generated within the banana's life cycle are usually calculated by multiplying the observed nitrogen content of nitrogenous fertilizer, applied by the factor 0.02. This fixed factor was determined by the IPCC (IPCC, 2006) and is applied in IPCC and FAO studies for calculating the agricultural emissions (Table 50) that are based on the agriculture values set by the World Resources Institute (Tables 51 and 9). The fixed factor is applied consistently to arable agricultural activities across the full range of soils and climatic conditions. On a global scale, where a simple standard method is necessary, this fixed factor is considered an appropriate approximation; variations above and below this imputed global mean largely cancel each other when aggregated on a large scale.

The use of this fixed factor in specific applications, however, can be misleading. First, it may over- or under-estimate actual N_2O emission levels. Second, it can lead to the assumption that the relationship between applied nitrogen and N_2O emissions is fixed and to the erroneous conclusion that the sole means of reducing N_2O emissions is through the lesser application of nitrogen. In fact, the relationship between applied nitrogen and N_2O emissions is not fixed. A growing body of research has found that agricultural N_2O emissions are proportional to the inventory of surplus nitrogen in the soil, rather than to the total amount of nitrogen applied.[61] Surplus nitrogen is the stock of nitrogen in the soil in excess of plant nitrogen uptake.[62] Thus, closer synchronization of nitrogen applications to plant nitrogen uptake would reduce the surplus of nitrogen in the soil, increase the proportion of applied nitrogen utilized by plants and reduce the proportion emitted as N_2O. Cassman *et al*. (2002: 139) provides a summary statement:

---

well as develop information on the best management practices relating to fertilizer use. These efforts would represent a partial, indirect rebate of the fertilizer tax to the banana sector.

[60] Ribaudo *et al*. (2011: 39-43) discusses the problems associated with fertilizer taxation. The study notes that several states in the United States have imposed fertilizer levies, which have not been effective in reducing nitrogen-related emissions.

[61] Recent studies include Grassini and Cassman (2012), Venterea *et al*. (2012), Hoben *et al*. (2011) and van Groenigen *et al*. (2010). A seminal contribution is Cassman *et al*. (2002), which is a useful starting point to this literature, as are Paustian *et al*. (2004), Mosier *et al*. (2004) and Grassini and Cassman (2012). For studies focused on bananas and Ecuador, see Corre *et al*. (2013), Borbor-Cordova *et al*. (2006) and Veldkamp and Keller (1997).

[62] The amount of surplus nitrogen is not easily observed. This justifies the use of the more observable quantity of applied nitrogen as a practical approximation by the IPCC.

> "[W]e see the greatest gains in NUE [nitrogen use efficiency] and environmental protection accruing from 'precision management' in time and space of all production factors to maximize the synchrony between crop-N demand and the supply of mineral N from soil reserves and N inputs … Such precision-management approaches will be required for both large-scale agriculture in developed countries and small-scale farming in developing countries. Balancing N demand and supply will require breakthroughs in fundamental understanding of crop and soil ecology and organic geochemistry to allow development of dynamic and cost-effective N-management approaches."

If the estimates of the nitrogen uptake rates for bananas (under local conditions) and the determinants (e.g. moisture, temperature) are correct, the benefits of closer synchronized nitrogen applications can be balanced against the cost of the additional applications. In addition, the optimal economic application profile can be determined. The banana sector in Ecuador lacks the necessary research and incentives to manage fertilizer use in order to minimize surplus soil nitrogen. It is important, therefore, to disseminate more information in this context. This would provide the benefits of reducing the unfavourable externalities of nitrogenous fertilizers (N_2O emissions and leaching) and of increasing the efficiency of fertilizer in the growing of bananas. Best practices in managing fertilizer (including the objective of GHG emissions mitigation) should be developed for specific regions in terms of the relative soil and climate and the information should be disseminated. Furthermore, the testing for nitrogen content in soil and plant tissue would provide data for the appropriate applications of nitrogen fertilizer. Civil engagement and perhaps the full or partial provision of such testing may be warranted.

5.4 Organic versus conventional bananas

Policies that encourage organic growing in lieu of the conventional growing of bananas often are advocated as a means to reduce GHG emissions. As indicated in Table 53, a shift from conventional to organic growing could result in a 20 percent average drop in terms of on-farm emissions. It is important to examine, in greater detail, the difference between conventional and organic production in relation to the GHG emissions (Table 54).[63] The total difference in the emissions is 62.6 kg/t. The emission-contributing factors are ranked by the amount of GHG emission change.

The most significant reduction in emissions relates directly to those from N_2O and fertilizers; together, they account for -93.7 kg/t of GHG emissions. The balance (-4.5 kg/t) is a result of more efforts to recycle, less electricity used, less packaging and the elimination of two classes of insecticide: Bifentrine and Chlorpyrifos. It is important to note that while insecticides pose a major environmental and human health risk, they have very little impact on the carbon footprint of the banana.[64] Organic methods of growing emanate slightly greater

---

[63] Table 54 provides more detail in relation to the summary data in Table 53. Table 54 examines those factors that have changed and excludes the source of the emissions, which are the same for organic and conventional methods.

[64] Chapter 1 addresses the importance of sustainability relating to the production of bananas.

Table 54 On-farm GHG emissions for Ecuador's bananas (kgCO$_2$e/t)

	Conventional	Organic	Difference	
N_2O direct emissions	100.4	41.1	-59.3	
Fertilizers	46.3	11.9	-34.4	-93.7
Recycling of plastic crop protection items	-2	-3.7	-1.7	
Electricity	2.5	1	-1.5	
Packaging	81.2	80.4	-0.8	
Bifentrine (crop protection mat, insecticide)	0.4	0	-0.4	
Chlorpyrifos (crop protection mat. insecticide)	0.1	0	-0.1	-4.5
Pesticides	7.8	8.1	0.3	
Fertilizer and pesticide transport	4.4	4.7	0.3	
Crop protection material	4.6	6.1	1.5	+2.1
Fossil fuels	7.6	11	3.4	
Oil (pesticide blending and cableway)	9.4	17.9	8.5	
Fossil CO_2 direct emissions	46.2	67.8	21.6	+33.5
Total			**-62.6**	**-62.6**

Source: Hospido and Roibás, Chapter 4)

GHG emissions from pesticides and do so more from crop protection material. Almost 95 percent of the emissions derive from the intensive use of fossil fuels, compared to conventional methods of growing. In summary, a shift from conventional to organic methods would contribute to a little more than one third drop in the emissions from fertilizer. Therefore, N_2O would be offset by the emissions from a more intensive use of fossil fuels.

The data in Table 54 indicate that considerably less N_2O would emanate if current conventional methods of growing were improved. It is not known, however, whether organically grown bananas are a sufficiently profitable alternative to conventionally grown ones, nor is it known whether there is a sufficient demand for organic bananas to absorb what would be a considerable shift from conventional to organic growing. In terms of economics, a large increase in the supply of organic bananas would squeeze the premium in the price. On the supply side, the limiting factor may be the availability and cost of additional labour that are required for the growing of organic bananas.

6. Summary

The key sources of on-farm GHG emissions relating to the growing of bananas are fertilizers, packaging and fossil fuel. Fertilizer and nitrous oxide are, by far, the most significant. N_2O emissions can best be reduced by encouraging the adoption of best management practices for fertilizer use, as well as testing the soil and plant tissue for nitrogen content. Reducing excess soil nitrogen can decrease N_2O emissions without reducing yields and it would result in a drop in the cost of production.

Packaging is the second main source of on-farm GHG emissions. Packaging, however, is largely outside the scope of Ecuador's policy-making, given that a change in packaging design would require acceptance at each stage in the supply chain, from farm to retail. Nevertheless, Ecuador can encourage innovations in packaging by collaborating with stakeholders within the supply chain in order to lessen the carbon footprint of the banana.

Fossil fuel, the third major source of on-farm emissions should be taxed. Alternatively, the price of fuel can be raised to encourage producers and domestic transporters to conserve energy and invest in more energy-efficient equipment.

©FAO/Aziz Elbehri

BIBLIOGRAPHY

ACS (American Chemical Society). 2012. Good News for Banana Lovers: Help May Be on the Way to Slow That Rapid Over-Ripening. ACS Press release (22 August 2012). http://www.acs.org/content/acs/en/pressroom/newsreleases/2012/august/good-news-for-banana-lovers-help-may-be-on-the-way-to-slow-that-rapid-over-ripening.html.

AEBE (Asociación de Exportadores de Banano del Ecuador). 2010. *Reporte Sobre la Industria Bananera Ecuatoriana, Año 2010*. Guayaquil, Ecuador.

AEBE (Asociación de Exportadores de Banano del Ecuador). 2011. *La Industria Bananera Ecuatoriana, Año 2011.*http://www.aebe.ec/data/files/noticias/Noticias2012/AEBE/INDUSTRIA_BANANERA_2011_3_%20jul18.pdf. Accessed 08/11/2013.

AEBE (Asociación de Exportadores de Banano del Ecuador**).** 2014. *Estadísticas Sobre la Industria Bananera Ecuatoriana, Año 2014. Guayaquil, Ecuador* (available at http://www.aebe.ec/).

Allen, R.G., Pereira, L.S., Raes, D. & Smith, M. 1998. *Crop Evapotranspiration-Guidelines for Computing Crop Water Requirements* - FAO Irrigation and Drainage paper 56. *In* FAO, Rome. 6541 p.

Arias-Hidalgo, M., Villa-Cox, G., van Griensven, A., Solórzano, G., Villa-Cox, R., Mynett, A.E. & Debels, P. 2013. A Decision Framework for Wetland Management in A River Basin Context: The "Abras De Mantequilla" Case Study in the Guayas River Basin, Ecuador. *Environmental Science & Policy* (forthcoming).

Arteaga, M. 2000. *Análisis Estadístico de la Producción Bananera en el Ecuador*. Tesis Ing. Estadística. Informática. Guayaquil. Escuela Superior Politécnica del Litoral. Inst. Cien. Mat. 221 p.

Ballot, E. & Fontane, F. 2010. Reducing Transportation CO_2 Emissions through Pooling of Supply Networks: Perspectives from a Case Study in French Retail Chains. *Production Planning & Control*, 21(6), 640-650.

Banana Link. *Banana Link*. http://www.bananalink.org.uk.

Banco Central del Ecuador. 1992, *El Ecuador de la Postguerra: Estudios en Homenaje a Guillermo Pérez Chiriboga* [*Post-War Ecuador: Studies in Honor of Guillermo Pérez Chiriboga*] Quito, Banco Central del Ecuador, p. 151.

Bassoi, L.S.H., Teixeira, A.H.D.C., Lima Filho, J.M.P., Silva, E.E.G.D., Ramos, C.M.C. & Sediyama, G.C**.** 2004. Guidelines For Irrigation Scheduling Of Banana Crop In SÃ£O Francisco Valley, Brazil. II - Water Consumption, Crop Coefficient, And Physiologycal Behavior. *Revista Brasileira de Fruticultura*. 26:464-467.

Berners-Lee, M**.** 2010. *How bad are bananas?: The carbon footprint of everything*. London, UK: Profile Books Ltd.

Berners-Lee, M., & Hoolohan C. 2012. *The Greenhouse Gas Footprint of Booths*. Lancaster, UK: Small World Consulting Ltd. http://www.booths.co.uk.

Bodansky, D. 2011. *Multilateral Climate Efforts Beyond the UNFCCC. Center for Climate and Energy Solutions* (C2ES) Policy Paper. Arlington, VA: C2ES.

Boletín de Información Comercial Española. 2011. Chapter 6. Ministerio de Industria, Turismo y Comercio (MITYC). http://www.revistasice.com/CachePDF/BICE_3015_99-126__33B6BB795F3CFBE6C08E02FBBA4200F9.pdf. Accessed 15 September 2014.

Borbor-Cordova, M. J., Boyer, E.W., McDowell, W.H. & Hall, C.A. 2006. Nitrogen and Phosphorus Budgets for a Tropical Watershed Impacted by Agricultural Land Use: Guayas, Ecuador. *Biogeochemistry*, 79(1-2), 135-161.

Bradley, R., Vuille, M., Diaz, H.F. & Vergara, W. 2006. Threats to Water Supplies in the Tropical Andes. *Science*, 312 (23 June):1755-56.

Brenton, P., Edwards-Jones, G. & Jensen, M.F. 2009. Carbon Labelling and Low-Income Country Exports: A Review of the Development Issues. *Development Policy Review*, 27:243–267.

Buhaug, Ø., Corbett, J.J., Endresen, Ø, Eyring, V., Faber, J. Hanayama, S. Lee, D.S., Lee, D. Lindstad, H., Markowska, A.Z., Mjelde, A. Nelissen, D., Nilsen, J., Pålsson, C., Winebrake, J.J., Wu, W.Q. & Yoshida, K. 2009. *Second IMO GHG Study 2009*. London: International Maritime Organization.

Business Energy Advisor. 2013. http://bea.tva.esource.com/warehouses. energyright solutions. Accessed 30 October 2013.

Cassman, K.G., Dobermann, A. & Walters, D.T. 2002. Agroecosystems, Nitrogen-Use Efficiency, and Nitrogen Management. *Ambio*, 31:132–140.

CEPAL (Comisión Económica para América Latina de las Naciones Unidas). 1998. *Ecuador: Evaluación de los Efectos Socioeconómicos del Fenómeno El Niño en 1997-1998.* S.I. 69 p.

Chadderton, D. 2013. Building Services Engineering. 6th Edition (2013). New York, Routledge.

Chambron, A.C. 2000. Straightening the Bent World of Bananas, *Banana Link,* EFTA, Brussels.

Chevallier, P., Pouyaud, B., Suarez, W. & Condom, T. 2011. Climate Change Threats to Environment in the Tropical Andes: Glaciers and Water Resources. *Regional Environmental Change*, 11(1):179-187.

Collins, M., An, S.N., Cai, W., Ganachaud, A., Guilyardi, E., Jin, F.F., Jochum, M., Lengaigne, M., Power, S. Timmermann, A., Vecchi, G. & Wittenberg, A. 2010. The Impact of Global Warming on the Tropical Pacific Ocean and El Niño. *Nature Geoscience*, 3:391-397.

Conde, C., Vinocur, M., Guy, C., Seiler, R. & Estrada, F. 2006. Climatic Threat Spaces as a Tool to Assess Current and Future Climate Risks: Case Studies in Mexico and Argentina. Assessments of Impacts and Adaptations to Climate Change. Assessments of Impacts and Adaptations to Climate Change (AIACC). Working Paper No. 30. Washington D.C.

Corporación Editora Nacional, Ecuador. 1987. *El Banano en el Ecuador: Transnacionales, Modernización y Subdesarrollo*. Biblioteca de Ciencias Sociales. 16:67-110.

Corre, M. D., Sueta, J.P. & Veldkamp, E. 2013. Nitrogen-Oxide Emissions from Tropical Forest Soils Exposed to Elevated Nitrogen Input Strongly Interact with Rainfall Quantity and Seasonality. *Biogeochemistry* (26 September, online first):1-18.

CPC (Climate Prediction Center). 2014. Changes to the Oceanic Niño Index (ONI). Cold and warm episodes by season. (Available at http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml).

Craig, A.J., Blanco, E.E. & Sheffi, Y. 2012. *A Supply Chain View of Product Carbon Footprints: Results from the Banana Supply Chain*. MIT-Engineering Systems Division (ESD): ESD Working Paper 2012-25. Cambridge MA: MIT. esd.mit.edu/wps.

Doka G. 2007. Life Cycle Inventories of Waste Treatment Services. Final Report. EcoInvent v2.1 No. 13. Swiss Centre for Life Cycle Inventories, Dübendorf, Switzerland.

Druckman, A., Chitnis, M., Sorrell, S. & Jackson, T. 2011. Missing Carbon Reductions? Exploring Rebound and Backfire Effects in UK Households. *Energy Policy,* 39:3572–3581.

Edwards-Jones, Milà i Canals, L., Hounsome, N., Truninger, M., Koerber, G., Hounsome, B., Cross, P.A., York, E.H., Hospido, A., Plassmann, K., Harris, I.M., Edwards, R.T., Day, G.A.S., Tomos, A.D., Cowell, S.J. & Jones, D.L. 2008. Testing the Assertion that 'local food is best': The Challenges of an Evidence-Based Approach. *Trends in Food Science & Technology*, 19, 265-274.

Eitner, A., Echao, C. & Leer, W. 2012. Carbon Footprint Report on Five Banana Supply Chains for TASTE/Agrofair B.V.

Emile-Geay, J., Cobb, K.M., Mann, M.E. & Wittenberg, A.T. 2013a. Estimating Central Equatorial Pacific SST Variability over the Past Millennium. Part I: Methodology and Validation. *Journal of Climate,* 26(7):2302-2328.

Emile-Geay, J., Cobb, K.M., Mann, M.E. & Wittenberg, A.T. 2013b. Estimating Central Equatorial Pacific SST Variability over the Past Millennium. Part II: Reconstructions and Implications. *Journal of Climate*, 26(7):2329–2352.

European Commission. 2013. European Commission Proposes to Overhaul Energy Taxation Rules. http://ec.europa.eu/taxation_customs/taxation/excise_duties/energy_products/legislation/.

FAO. http://www.fao.org/economic/est/est-commodities/bananas/banana-prices/en/

FAO. 1986. The World Banana Economy: 1970-1984. Commodities and Trade Division. Rome. 146 p.

FAO. 1992. CROPWAT: A computer program for irrigation planning and management. Rome

FAO. 2001. *CropWat for Windows: User Guide*. Rome.

FAO. 2003. *The World Banana Economy 1985-2002*, Commodity and Trade Division. Rome.

FAO. 2013, *Livestock's Long Shadow: Environmental Issues and Options*. Animal Production and Health, No. 177. Rome.

FAO. 2014. *Carbon Footprint along the Ecuadorian Banana Supply Chain: Methodological Improvements and Calculation Tool.* Rome. (forthcoming).

FAO. Life Cycle Assessment of Tea Produced in Kenya, Rome (forthcoming).

Fieldhouse, A. & Thiess, R. 2013. *The 'Back to Work' Budget: Analysis of the Congressional Progressive Caucus Budget for Fiscal Year 2014*. Washington: Economic Policy Institute.

Fairtrade Labelling Organizations International. 2009: Annual Report 2009-10, Bonn, Germany.

Fortescue, J.A., Turner, D.W. & Romero, R. 2011. Evidence that Banana (Musa Spp.), A Tropical Monocotyledon, Has a Facultative Long-Day Response to Photoperiod. Functional Plant Biology. 38:867-878.

Freitas, W.D.S., Ramos, M.M. & Costa, S.D. 2008. Demanda de irrigasao da cultura da banana na bacia do Rio Sao Francisco. *Revista Brasileira de Engenharia Agricola e Ambiental*. 12:343-349.

Freshfruitportal.com. 2010. Ecuador Banana Production Drops up to 40 percent due to Cold Weather. (Available at http://www.freshfruitportal.com/2010/11/16/ecuador-banana-production-drops-up-to-40-due-to-cold-weather/?country=nicaragua. Accessed on 14 December 2013).

Frischknecht R., N. Jungbluth, H.-J. Althaus, G. Doka, R. Dones, R. Hirschier, S. Hellweg, S. Humbert, M. Margni, T. Nemecek & M. Spielmann. 2007. Ecoinvent Reports, Nos. 1-25.

FruTrop online. 2011. *Direct from the Markets*. Cirad revue. FruTrop N° 191. p 5.

Gasparotto, L. & Pereira, J.C.R. 2008. Impacto Potencial das Mudanças Climáticas sobre as Doenças da Bananeira no Brasil. *In* R. Ghini R. and E. Hamada, eds. *Mudanças Climáticas: Impactos sobre Doenças de Plantas no Brasil*, pp. 201-6. Brasília, Brazil: Embrapa.

Ghini, R., Hamada, E., Goncalves, R.R.V., Gasparotto, L., & Pereira, J.C.R., 2007. Análise de risco das mudanças climáticas globais sobre a sigatoka-negra da bananeira no Brasil. *Fitopatologia Brasileira***,** v.32, p.197-204.

Ghini R, Bettiol W, Hamada E. 2011. Diseases in tropical and plantation crops as affected by climate changes: current knowledge and perspectives. *Plant Pathology* 60, 122–32.

Goyal, S.K. & Giri, B.C. 2001. Recent Trends in Modeling of Deteriorating Inventory. *European Journal of Operational Research*, 134:1–16.

Grainger, C.A. & Kolstad, C.D. 2010. Who Pays a Price on Carbon? *Environmental and Resource Economics*, 46(3):359-376.

Grassini, P. & Cassman, K.G. 2012. High-Yield Maize with Large Net Energy Yield and Small Global Warming Intensity. *Proceedings of the National Academies of Science* 109(4):1074-1079.

Green Cranes. 2013. *Green Technologies and Eco-Efficient Alternatives for Cranes and Operations at Port Container Terminals*. Report on Port Container Terminals Energy Profile. http://www.greencranes.eu/M2Report.pdf. Accessed 30 October 2013.

Hargreaves, G.H., & Allen, R.G. 2003. History and Evaluation of Hargreaves Evapotranspiration Equation. *Journal of Irrigation and Drainage Engineering*. 129:53-63.

Harris, I., Jones, P.D., Osborn, T.J. & Lister, D.H. 2013. Updated High-Resolution Grids of Monthly Climatic Observations. In press, *International Journal of Climatology*. Doi: 10.1002/joc.3711.

Hendel, I. & Nevo, A. 2006. Measuring the Implications of Sales and Consumer Inventory Behavior. *Econometrica*, 74(6):1637–1673.

Hertwich, E. G. & Peters, G.B. 2009. Carbon Footprint of Nations: A Global, Trade-Linked Analysis. *Environmental Science & Technology*, 43(16):6414-6420.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G. & Jarvis, A. 2005. Very High Resolution Interpolated Climate Surfaces for Global Land Areas. *International Journal of Climatology* 25:1965-1978.

Hoben, J. P., Gehl, R.J., Millar, N., Grace, P.R. & Robertson, G.P. 2011. Nonlinear Nitrous Oxide (N_2O) Response to Nitrogen Fertilizer in On-Farm Corn Crops of the US Midwest. *Global Change Biology*, 17(2), 1140-1152.

Human Rights Watch. 2002. *Tainted Harvest: Child Labor and Obstacles to Organizing on Ecuador's Banana Plantations.* New York.

IEA (International Energy Agency). 2010. *Ecuador: Electricity and Heat for 2010*. http://www.iea.org/statistics/statisticssearch/report/?&country=ECUADOR&year=2010&product=ElectricityandHeat. Accessed 30 October 2013.

IMO (International Maritime Organization). 2011. Breakthrough in IMO: Legally Binding Agreement to Reduce CO_2 Emissions from International Shipping. http://www.imo.org/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Breakthrought-at-MEPC-62.aspx.

INE (Instituto Nacional de Estadística). 2011. *Encuesta Sobre Recogida y Tratamiento de Residuos. Tratamiento de Residuos 2011*.

http://www.ine.es/jaxi/tabla.do?path=/t26/e068/p04/a2011/l0/&file=01002.px&type=pcaxis&L=0. Accessed 30 October 2013.

INE (Instituto Nacional de Estadística). 2012. Encuesta de Presupuestos Familiares. Cantidad Total y Cantidades Medias Consumidas de Alimentos, Bebidas, Tabaco, Combustibles y Otras Fuentes de Energía. http://www.ine.es/jaxiBD/menu.do?divi=EPF&per=01&type=db&his=12

Accessed 30 October 2013).

IPCC (Intergovernmental Panel on Climate Change). 2006, N_2O Emissions From Managed Soils and CO_2 Emissions from Lime and Urea Application.

In: *Agriculture, Forestry and Other Land Use*, Volume 4, Chapter 11 (eds E. Eggleston, L. Buendia, K. Miwa, T. Ngara & K. Tanabe). Kanagawa, Japan: Institute for Global Environmental Strategies.

IPCC (Intergovernmental Panel on Climate Change). 2007. *Climate Change 2007: The Physical Science Basis. Working Group I Contribution to the Intergovernmental Panel on Climate Change, Fourth Assessment Report*. Cambridge, United Kingdom, and New York: Cambridge University Press. http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm.

IPCC (Intergovernmental Panel on Climate Change). 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change.* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge, United Kingdom, and New York: Cambridge University Press.

IPCC (Intergovernmental Panel on Climate Change). 2014a. *Climate Change 2014: Impacts, Adaptation and Vulnerability. Volume 1: Global and Sectoral Aspects*. IPCC/WGO/UNEP.

IPCC (Intergovernmental Panel on Climate Change). 2014b. *Climate Change 2014: Impacts, Adaptation and Vulnerability. Volume 2: Regional Aspects*. IPCC/WGO/UNEP.

Jacome, L.H. & Schuh, W. 1992. Effects of Leaf Wetness Duration and Temperature of Development of Black Sigatoka Disease on Banana Infected by *Mycosphaerella fijiensis var. difformis*. *Phytopathology*, v.82, p.515-520.

Jacome, L.H., W. Schuh and R.E. Stevenson. 1991. Effect of Temperature and Relative Humidity on Germination and Germ Tube Development of *Mycosphaerella fijiensis var. difformis. Phytopathology*, v.12, p.1480-1485.

Jesus Júnior, W.C., Valadares Júnior, J.R., Cecílio, R.A., Moraes, W.B., Vale, F.X.R.D., Alves, F.R. & Paul, P. A. 2008. Worldwide Geographical Distribution of Black Sigatoka for Banana: Predictions Based on Climate Change Models. *Sciencia Agricola* 65:40–53.

Jones, C. M. & Kammen, D.M. 2011. Quantifying Carbon Footprint Reduction Opportunities for US Households and Communities. *Environmental Science & Technology*, 45(9):4088-4095.

Katz, R.W. 2002. Sir Gilbert Walker and a Connection between El Niño and Statistics. *Statistical Science*, 17(1):97-112.

Kilian, B., Hettinga, J., Jiménez, G.A., Molina, S., & White, A. 2012. Case Study on Dole's Carbon-Neutral Fruits. *Journal of Business Research*, 65(12), 1800-1810.

Kitinoja, L. & Kader, A.A. 2002. Small-Scale Post-Harvest Handling Practices: A Manual for Horticultural Crops. Fourth Edition. *Postharvest Horticulture Series,* No. 8E, 260 pp. Davis: University of California.

Kossoy, A., Oppermann, K., Reddy, R.C., Bosi, M. & Boukerche, S. 2013. *Mapping Carbon Pricing Initiatives: Developments and Prospects.* Washington, DC: The World Bank. http://documents.worldbank.org/curated/en/2013/05/17751166/mapping-carbon-pricing-initiatives-developments-prospects.

Knutson, T.R., McBride, J.L., Chan, J., Emanuel, K., Holland, G., Landsea, C., Held, I., Kossin, J.P., Srivastava, A.K. & M. Sugi. 2010. Tropical Cyclones and Climate Change. *Nature Geoscience*, 3(3):157-163.

LACENA (Latin America - Current Events & News, Agriculture). **Sopisco News,** *Outlook on the banana and reefer market*; various weekly issues: 2010-2013; Nova Media Publishing Inc., Panama.Various issues: 2010 to 2013.

Lange, P., Driessen, P., Sauer, A., Bornemann B. & Burger, P. 2013. Governing Towards Sustainability: Conceptualizing Modes of Governance. *Journal of Environmental Policy & Planning* Volume 15 (3): 403-425.

Lescot, T. 2012. *Carbon Footprint Analysis in Banana Production.* Second Conference of the World Banana Forum in Guayaquil, Ecuador. CIRAD. Montpellier. http://www.fao.org/fileadmin/templates/banana/documents/WGs_outputs/WG01/Carbon_Footprint_study_on_banana_Final_Oct12.pdf. Accessed 18 December 2013.

Li, J., Xie, S.P., Cook, E.R., Morales, M.S., Christie, D.A., Johnson, N.C., Chen, F., D'Arrigo, R., Fowler, A.M., Gou X. & Fang, K. 2013. El Niño Modulations over the Past Seven Centuries. *Nature Climate Change*, 3(9):822-826.

Luske, B. 2010. *Comprehensive Carbon Footprint Assessment: Dole Bananas*. Soil and More International B.V. http://dolecrs.com/uploads/2012/06/Soil-More-Carbon-Footprint-Assessment.pdf. Accessed 30 October 2013.

McKenzie, D. & Schargrodsky. E. 2011. Buying Less but Shopping More: The Use of Nonmarket Labor During a Crisis. *Economia*, 11(2):1-35.

McKinnon, A.C. 2008. *The Potential of Economic Incentives to Reduce CO_2 Emissions from Goods Transport.* Paper prepared for the First International Transport Forum on Transport and Energy: The Challenge of Climate Change. Leipzig. 28-30 May. www.internationaltransportforum.org/Topics/Workshops/WS3McKinnon.pdf.

Machovina, B. 2013. Climate Change Driven Shifts in the Extent and Location of Areas Suitable for Export Banana Production. Paper presented at Taller Nacional de Socialización del Estudio sobre "Producción y comercio de banano en el marco del Cambio Climático**,"** Guayaquil, Ecuador, January 21-22, 2014.

MAGAP (Ministerio de Agricultura, Ganaderia, Acuacultura y Pesca), Ecuador. 2013. *Catastro del Banano 2013.* Elaborado por: Dirección de Inteligencia Comercial e Inversiones. Ecuador.

MAGRAMA (Ministerio de Agricultura, Alimentación y Medio Ambiente), Spain. 2012. Barómetro del Clima de Confianza del Sector Agroalimentario. http://www.magrama.gob.es/es/alimentacion/temas/estrategia-mas-alimento-menos-desperdicio/Monog__Desperdicio_Alimentario_1er_trim_2%C2%BA_trim_y_4%C2%BA_Trim_2012_tcm7-287271.pdf. Accessed 16 September 2014.

Maldonado, Carlos Larrea, ed. 1987. *El Banano en el Ecuador: Transnacionales, Modernización y Subdesarrollo* [*The Banana in Ecuador: Transnationals, Modernization and Underdevelopment*] Quito: Corporación Editora Nacional, p. 45.

Marco Trade News. 2010. *Ecuadorian Banana Exports to Major Consumers Decrease but Are Compensated by Sales To EU*. (Available at: http://marcotradenews.com/mercados/17369/Ecuadorian-banana-exports-to-major-consumers-decrease-but-are-compensated-by-sales-to-EU. Accessed on 14 December 2013).

Martínez, H.A. 2009. *Estudios Proyecto para la Creación de un Centro de Acopio de Banano en el Municipio de Puli, Cundinamarca*. Escuela Superior de Adminstración Pública (ESAP). Facultad de Posgrados. Bogotá D.C. http://cdim.esap.edu.co/BancoConocimiento/E/estudios_proyecto_para_la_creacion_de_un_centro_de_acopio_de_banano_en_el_municipio_de_puli_cundinamarca/estudios_proyecto_para_la_creacion_de_un_centro_de_acopio_de_banano_en_el_municipio_de_puli_cundinamarca.asp. Accessed 30 October 2013.

Merchán Vargas V.M. 2002. Manejo Integrado de Plagas del Plátano y el Banano; In. *Proceedings XV ACORBAT Meeting 2002*; Cartagena de Indias, Colombia.

Ministerio de Salud Pública, Ecuador. n.d. *El Fenómeno El Niño en Ecuador*. 58 p.

Ministry of Finance, Province of British Columbia, Canada. 2013. Carbon Tax Review and Carbon Tax Overview. http://www.fin.gov.bc.ca/tbs/tp/climate/carbon_tax.htm.

Montalvo, C. 2008. La Estructura Vertical del Mercado Bananero Para el Ecuador Y el Carácter Limitado de las Reformas de Comercio Internacional. *Revista Tecnológica ESPOL*. 21(1):165-179.

Mosier, A., Syers J.K. & Freney, J.R. (Eds.) 2004. *Agriculture and the Nitrogen Cycle: Assessing the Impacts of Fertilizer Use on Food Production and the Environment*. SCOPE – Scientific Committee on the Problem of the Environment. Washington, D.C.: Island Press.

Muñoz, G. 2000. *Problemas y Retos del Sector Exportador Ecuatoriano ante la Proliferación de Restricciones Comerciales Ambientalistas.* Tesis Máster Rel. Econ. Int. Quito. Universidad Andina Simón Bolivar. 172 p.

Muñoz, I., Milá i Canals, L., Clift, R. & Doka, G. 2007. *Allocation Model for Human Excretion and Wastewater Treatment in Life Cycle Assessment of Food Products*. CES Working Papers 01/07.

Nahmias, S. 2011. *Perishable Inventory Systems*. New York, NY: Springer Science + Business Media.

NCAR (National Center for Atmospheric Research Staff) (eds). *The Climate Data Guide: Nino SST Indices*. Last modified 20 November 2013. Retrieved from https://climatedataguide.ucar.edu/climate-data/nino-sst-indices.

Neira, D. 2010. Ecuador: *Estado de Situación Frente a la Agricultura, Seguridad Alimentaria y Gestión de Recursos Hídricos Destinados a la Agricultura y el Cambio Climático*. Ecuador. 29 p.

Nemecek T., Kägi T. & Blaser S. 2007. Life Cycle Inventories of Agricultural Production Systems. Final report ecoinvent v2.0 No.15. Swiss Centre for Life Cycle Inventories, Dübendorf, Switzerland.

Noboa, E. 2014. *Gestión del Cambio Climático en el Ecuador: Taller Nacional de Socialización del Estudio sobre Producción y Comercio de Banano en el Marco del Cambio Climático*. Guayaquil, Ecuador. 21-22 January.

Notteboom, T. & Rodrigue. J-P. 2008. Containerisation, Box Logistics and Global Supply Chains: The Integration of Ports and Liner Shipping Networks. *Maritime Economics & Logistics*, 10(1):152-174.

Notteboom, T. & Rodrigue, J-P. 2009. The Future of Containerization: Perspectives from Maritime and Inland Freight Distribution. *Geojournal*, 74(1):7-22.

Paustian, K., Babcock, B., Kling, C., Hatfield, J., Lal, R., McCarl, B., McLaughlin, S., Post, W.M., Mosier, A., Rice, C., Robertson, P., Rosenberg, N.J., Rosenzweig, C., Schlesinger W.H. & Zilberman, D. 2004. *Agricultural Mitigation of Greenhouse Gases: Science and Policy Options*. Ames, IA: Council on Agricultural Science and Technology (CAST) Report R 141.

Peduzzi, P., Chatenoux, B., Dao, H., De Bono, A., Herold, C., Kossin, J., Mouton

F. & Nordbeck, O. 2012. Global Trends in Tropical Cyclone Risk. *Nature Climate Change*, 2(4):289–294.

Perrier, X. & Tezenas du Montcel, H. 1990. Musaid: A Computerized Determination System. p.76-91. In: Jarret, R.L. (ed.), *Identification of Genetic Diversity in the Genus Musa*, International Network for the Improvement of Banana and Plantain (INIBAP). Montpellier, France.

Pillay, M., Ude, G. & Kole, C. (eds.) 2012. *Genetics, Genomics and Breeding of Bananas*. Enfield, NH: Science Publishers/CRS Press.

Pindyck, R.S. 2011. Fat Tails, Thin Tails, and Climate Change Policy. *Review of Environmental Economics and Policy*, 5(2):258–27.

Pindyck, R.S. 2013. Climate Change Policy: What Do the Models Tell Us? NBER Working Paper No. 19244. Forthcoming in *Journal of Economic Literature*, 51(3):860-72.

Ploetz, R. C., Thomas, J.E. & Slabaugh, W.R. 2003. Diseases of Banana and Plantain. *In* R.C. Ploetz, ed. *Diseases of Tropical Fruit Crops*, pp. 73–134. Wallingford, UK: CAB International Publishing.

Ploetz, R.C. 2001. Diseases of tropical crops caused by *Fusarium* spp. pp. 295-309. in: B.A. Summerell, J.F. Leslie, D. Backhouse, and W.L. Bryden (eds.). *Fusarium*: Paul E. Nelson Memorial Symposium. APS Press.

Pérez, L., Mauri, F., Hernández, A., Abreu, A. & Porras, G. 2000. Epidemiología de la Sigatoka Negra (*Mycosphaerella fijiensis* Morelet) en Cuba. I. Pronóstico Bioclimático de los Tratamientos de Fungicidas en Bananos (*Musa acuminata* AAA). *Revista Mexicana de Fitopatología*, Vol. 18, No. 1, January-June. pp. 15-26, Sociedad Mexicana de Fitopatología, A.C.

Pérez, L., Mauri, F., Hernandez, A., Abreu, A. & Porras, G. 2006. *Relaciones entre los factores climáticos y la velocidad de evolución de la Sigatoka Negra en bananos y plátanos*. Memorias de XVII Reunión Internacional de ARCORBAT, Vol. 2. p. 702-709.

Porras, A. & Pérez, L. 1997. Efecto de la temperatura sobre el crecimiento de los tubos germinativos de las ascosporas de *Mycosphaerella* spp. causantes de Sigatoka en banano. *InfoMusa, 6*(2):27-31.

PROECUADOR. 2013. *Análisis del Sector Banano*. Report by Dirección de Inteligencia Comercial e Inversiones, Ecuador.

Psaraftis, H. N. & Kontovas, C.A. 2013. Speed Models for Energy-Efficient Maritime

Transportation: A Taxonomy and Survey. *Transportation Research Part C: Emerging Technologies*, 26, 331-351.

Rabatel, A., Francou, B., Soruco, A., Gomez, J., Cáceres, B., Ceballos, J.L., Basantes, R. Vuille, M. Sicart, J.E. Huggel, C. Scheel, M., Lejeune, Y., Arnaud, Y., Collet, M., Condom, T., Consoli, G., Favier, T., Jomelli, V., Galarraga, R., Ginot, P. Maisincho, L., Mendoza, J., Ménégoz, J., Ramirez, E., Ribstein, P., Suarez, W., Villacis, M. & Wagnon, P. 2013. Current State of Glaciers in the Tropical Andes: A Multi-Century Perspective on Glacier Evolution and Climate Change. *The Cryosphere*, 7(1):81-102.

Rabobank. 2001. Fruit Traders in Trouble, Industry Note, issue 002-2001, Utrecht, The Netherlands.

Ramírez, J. & Jarvis, A. 2008. High Resolution Statistically Downscaled Future Climate Surfaces. International Center for Tropical Agriculture (CIAT); CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Cali, Colombia.

Ramirez, J., Jarvis, A., Van den Bergh, I., Staver, C. & Turner, D. 2011. Changing Climates: Effects on Growing Conditions for Banana and Plantain (Musa spp.) and Possible Responses. *In* S. Yadav, B. Redden, J.L. Hattfield and H. Lotze-Campen (eds.), *Crop Adaptation to Climate Change*, pp. 426-438. Chichester, UK: Wiley-Blackwell.

Ribaudo, M., Delgado, J., Hansen, L., Livingston, M., Mosheim, R. & Williamson, J. 2011. *Nitrogen in Agricultural Systems: Implications for Conservation Policy*. Washington D.C.: United States Department of Agriculture, Economic Research Service.

Robinson, P.K. 2010. Do Voluntary Labour Initiatives Make A Difference for the Conditions of Workers in Global Supply Chains? *Journal of Industrial Relations,* Volume 52(5): 561-573.

Robinson, J.C. & Gálan Saúco, V. 2010. *Bananas and Plantains*. 2nd edition. Wallingford UK: CAB International.

Rodrigue, J-P., Comtois, C. & Slack, B. 2013. *The Geography of Transportation Systems.* Abingdon, UK: Routledge. http://people.hofstra.edu/geotrans/index.html.

Rodríguez-García, G., Hospido A., Bagley, D.M., Moreira, M.T., & Feijoo, G. 2012. A Methodology to Estimate Greenhouse Gases Emissions in Life Cycle Inventories of Wastewater Treatment Plants. *Environmental Impact Assessment Review* 37:37-46.

Roquigny, S., Vagneron, I., Lescot, T. & Loeillet, D. 2008. *Making the Rich Richer? Value Distribution in the Conventional, Organic and Fair Trade Banana Chains of the Dominican Republic*, Paper No. 68, presented at the Fair Trade International Symposium, CIRAD, Montpellier, France.

Siles, P., Vaast, P., Dreyer, E. & Harmand, J.M. 2010. Rainfall Partitioning into Throughfall, Stemflow and Interception Loss in a Coffee (Coffea Arabica L.) Monoculture Compared to an Agroforestry System with Inga Densiflora. *Journal of Hydrology*.

Silva, E.D. & Bezerra, F. 2009. Evapotranspiration and Crop Coefficients of Banana at the Vale of Curu, CE, Brazil. *Revista Ciencia Agronomica*. 40:203-210.

Simmonds, N.W. & Shepherd, K. 1955. The Taxonomy and Origins of the Cultivated Bananas. *Botanical Journal of the Linnean Society*, 55:302-312.

Solow, A.R. and Moore, L.J. 2002. Testing for Trend in North Atlantic Hurricane Activity, 1900–98. *Journal of Climate*, 15:3111–3114.

Spielmann M., Dones R. & Bauer C. 2007. *Life Cycle Inventories of Transport Services*. Final Report EcoInvent v2.0 No. 14. Swiss Centre for Life Cycle Inventories, Dübendorf, Switzerland.

Stover, R.H. & Simmonds, N.W. 1987. *Bananas.* 3rd Ed. Longman Scientific and Technical. Essex, UK. p. 468.

Svanes, E. 2012. *KLIMAT – A Norwegian Research Project*. Report from the Banana Case Study. OR.07.12. Østfoldforskning, Norway.

Svanes, E., & Aronsson, A. 2013. Carbon footprint of a Cavendish banana supply chain. The International Journal of Life Cycle Assessment 18:1450–1464.

Tassou S.A., Ge, Y, Hadawey, A, Marriott, D. 2010. Energy Consumption and Conservation in Food Retailing. Applied Thermal Engineering.

doi:10.1016/j.applthermaleng.2010.08.023.

Terminal Puerto Arica, S.A. 2011. *Reporte de Gases Efecto Invernadero*. http://www.tpa.cl/. Accessed 18 November 2013.

Thomas, D.S., Turner, D.W. & Eamus, D. 1998. Independent Effects of the Environment on the Leaf Gas Exchange of Three Banana (Musa Sp.) Cultivars of Different Genomic Constitution. *Scientia Horticulturae*. 75:41-57.

Tonnang, E.Z.H., Carhuapoma, P., Juarez, H., Gonzales, J.C., Sporleder, M., Simon, R. & Kroschel, J. 2013. *Insect Life Cycle Modeling: A Software Package for Developing Temperature-Based Insect Phenology Models with Applications for Regional and Global Analysis of Insect Population and Mapping*, International Potato Center, Lima, Peru. pp 193.

Trajkovic, S. 2007. Hargreaves versus Penman-Monteith under Humid Conditions. *Journal of Irrigation and Drainage Engineering.* 133:38-42.

Tukker, A. & Jansen, B. 2006. Environmental Impacts of Products: A Detailed Review of Studies. *Journal of Industrial Ecology,* 10(3):159-182.

Turner, D. & Lahav, E. 1983. *The Growth of Banana Plants in Relation to Temperature. Functional Plant Biology*. 10:43-53.

Umpierrez, O. n.d. *Análisis de impactos hidrológicos de "El Niño" – Compilación, estudios e investigación*. S.I. 31 p.

United States Government. 2013. Interagency Working Group on Social Cost of Carbon. Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866. http://www.whitehouse.gov/sites/default/files/omb/inforeg/social_cost_of_carbon_for_ria_2013_update.pdf.

United States House of Representatives, Committee on Energy & Commerce (Democrats). 2013. *Waxman, Whitehouse, Blumenauer, and Schatz release carbon price discussion draft*. 12 Mar 12, 2013. http://democrats.energycommerce.house.gov/index.php?q=news/waxman-whitehouse-blumenauer-and-schatz-release-carbon-price-discussion-draft.

Van den Bergh, I., Ramirez, J., Staver, C., Turner, D.W., Jarvis, A. & Brown, D. 2010. Climate Change in the Subtropics: The Impacts of Projected Averages and Variability on Banana Productivity. In *XXVIII International Horticultural Congress on Science and Horticulture for People (IHC2010).* International Symposium on 928 (pp. 89-99).

Van den Bergh, I., Amorim, E.P. & Johnson, V. (eds.) 2013. *International ISHS-ProMusa Symposium on Bananas and Plantains: Towards Sustainable Global Production and Improved Use 986.* Leuven, Belgium: International Society for Horticultural Science.

Van den Bergh, I., Ramirez, J., Staver, C., Turner, D.W., Jarvis, A. & Brown, D. 2012. *Climate Change in the Subtropics: The Impacts of Projected Averages and Variability on Banana Productivity*. Acta Horticulturae (ISHS) 928:89-99.

van Groenigen, J.W., Velthof, G., Oenema, O., van Groenigen, K.J. & van Kessel,

C. 2010. Towards an Agronomic Assessment of N_2O Emissions: A Case Study for Arable Crops. *European Journal of Soil Science*, 61:903–913.

Vanzetti, D., Fernandez de Cordoba, S. & Chau V**.** 2005. Banana Split. How EU Policies

Divide Global Producers, *Policy Issues in International Trade and Commodities*. Study Series No. 31. UNCTAD, New York & Geneva.

Veldkamp, E. & Keller, M. 1997. Nitrogen Oxide Emissions from a Banana Plantation in the Humid Tropics. *Journal of Geophysical Research,* 102 (D13):15889-15898.

Venterea, R. T., Halvorson, A.D., Kitchen, N.R., Liebig, M.A., Cavigelli, M.A., Grosso, S.J.D., Motavalli, P.P., Nelson, K.A. Spokas, K.A., Singh, B.P., Stewart, C.E., Ranaivoson, A. Strock, J. & Collins, H. 2012. Challenges and Opportunities for Mitigating Nitrous Oxide Emissions from Fertilized Cropping Systems. *Frontiers in Ecology and the Environment*, 10(10), 562-570.

Vorley, B. 2003. *Food, Inc: Corporate Concentration from Farm to Consumer*. UK Food Group. London.

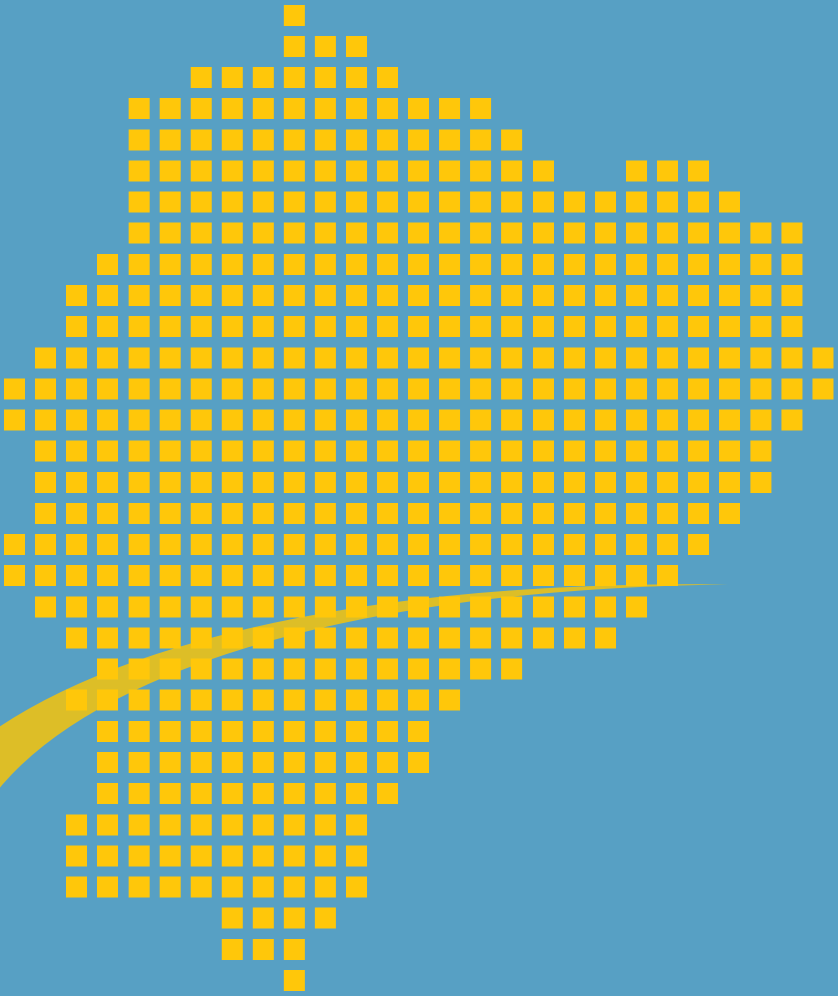
Weber, C.L. & Matthews, H.S. 2008. Food-Miles and the Relative Climate Impacts of Food Choices in the United States. *Environmental Science & Technology*, 42 (10):3508-3513.

World Bank. 2013. *Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience. A Report for the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics*. Washington, D.C.

http://documents.worldbank.org/curated/en/2013/06/17862361/turn-down-heat-climate-extremes-regional-impacts-case-resilience-full-report.

Wunder, S. 2001. Ecuador Goes Bananas: Incremental Technological Change and Forest Loss. In A. Angelsen and D. Kaimowitz, eds. *Agricultural Technologies and Tropical Deforestation,* pp. 167-194. Wallingford UK: CAB International.

WW2010. 2010. *El Niño*. Department of Atmospheric Science. University of Illinois. (Available at http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/eln/def.rxml. (Accessed on 14 December 2013).



ISBN 978-92-5-109249-1

9 789251 092491

I5697E/1/05.16