A Compilation of Tools and Methodologies to Assess the Sustainability of Modern Bioenergy

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BEFSCI
Bioenergy and Food Security
Criteria and Indicators

FOREWORD

The global demand for modern bioenergy, and especially liquid biofuels, is rapidly growing, driven mainly by climate change mitigation policies and increasing oil prices. This creates both opportunities and risks for developing countries.

On one hand, modern bioenergy development can boost both agricultural and rural development, by raising agricultural productivity, creating new employment and income-generating opportunities, and improving access to modern energy services in rural areas. On the other hand, if not properly managed, modern bioenergy development can trigger a number of negative environmental and socio-economic impacts, for instance by putting pressure on key resources such as land and water.

The environmental and socio-economic sustainability of modern bioenergy has been highly debated over the past few years. One of the most controversial issues that has dominated this debate is the relationship between bioenergy and food security.

In order to shed light on this complex issue and help policy-makers understand and manage the risks and opportunities for food security associated with various bioenergy development pathways, the FAO's Bioenergy and Food Security (BEFS) project developed an Analytical Framework and a toolbox, which are being implemented in several countries.

Building on this work, the FAO's Bioenergy and Food Security Criteria and Indicators (BEFSCI) project has developed a set of criteria, indicators, good practices and policy options on sustainable bioenergy development that foster rural development and food security. BEFSCI aims to inform the development of national frameworks aimed at preventing the risk of negative impacts - and increasing the opportunities - of bioenergy development on food security; and help developing countries monitor and respond to the impacts of bioenergy development on food security.

In order to ensure that modern bioenergy is sustainable and that it fosters rural development and food security, both the sector as a whole and individual operations need to be developed in a way that minimizes the risk of future negative impacts and increases the opportunities. Once the sector or a specific operation have been established, the resulting environmental and socio-economic impacts need to be monitored.

The BEFSCI project has compiled a set of thirty relevant tools and methodologies that can be used to inform the development of sustainable bioenergy policies, strategies and operations, and to assess, both ex-ante and ex-post, the main environmental and socio-economic impacts arising from individual operations or from the bioenergy sector as a whole.

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INTRODUCTION

The FAO's Bioenergy and Food Security Criteria and Indicators (BEFSCI) project (see box 1) has compiled a set of thirty relevant tools and methodologies that can be used to inform the development of a sustainable bioenergy sector and of sustainable operations, and to assess, both *ex-ante* and *ex-post*, the main environmental and socio-economic impacts arising from individual operations or from the bioenergy sector as a whole.

Modern bioenergy development, through its environmental and socio-economic impacts, may have positive or negative effects (both direct and indirect) on the four dimensions of food security: availability, access, utilization and stability (see box 2).

For instance, bioenergy may create new employment and income-generating opportunities, with positive effects on people's access to food. At the same time, if good practices are not implemented, bioenergy production may lead to negative impacts on the productive capacity of land or on water availability and quality, with negative repercussions on food security.

Both the nature and magnitude of the impacts of modern bioenergy development on food security will depend on a number of factors, related mainly to the type of feedstock and bioenergy technology considered, the way production is managed, and the environmental, socio-economic and policy context in which such development takes place.

BOX 1. FAO'S BIOENERGY AND FOOD SECURITY CRITERIA AND INDICATORS (BEFSCI) PROJECT

Building on the Bioenergy and Food Security (BEFS) Analytical Framework, the BEFSCI project has developed a set of criteria, indicators, good practices and policy options on sustainable bioenergy production that foster rural development and food security, in order to:

- inform the development of national frameworks aimed at preventing the risk of negative impacts - and increasing the opportunities - of bioenergy developments on food security; and
- help developing countries monitor and respond to the impacts of bioenergy developments on food security and its various dimensions and sub-dimensions.

Some of the impacts (both positive and negative) of bioenergy production on food security may arise from - and be attributed to - specific bioenergy projects and operations. Most of these impacts will be localized in and around bioenergy production areas. Examples of these are the impacts on soil quality in bioenergy feedstock production areas.

Other impacts of bioenergy production on food security will be the result of the cumulative effects of the domestic bioenergy sector. These impacts, which may not be attributed to specific bioenergy projects and operations, will have macro-level implications, some of which will have repercussions on local food security as well. Examples of these are the impacts of bioenergy production on the prices of staple crops.

A third category entails the local-level impacts attributable to specific bioenergy projects and operations, which may also trigger impacts at larger scales. For instance, each individual bioenergy project or operation may affect local water availability. In addition, the overall use of - and pressure on - water resources by all bioenergy projects and operations combined may compete with other water uses and affect water availability at larger scales (e.g. basin/watershed level), even if each individual bioenergy project and operation uses water efficiently.

In order to ensure that modern bioenergy development is environmentally and socially sustainable and that it fosters rural development and food security, the aforementioned impacts need to be assessed at both national and operator levels by the relevant stakeholders, during both planning and monitoring phases.

The thirty tools and methodologies that BEFSCI has compiled can be used to conduct these impact assessments, as well as to inform the development of sustainable bioenergy policies, strategies and investments.

These science-based tools and methodologies, which can be used by governments, operators and any other interested stakeholders, were selected based on their relevance (especially in terms of applicability to bioenergy), practicality and replicability.

The thirty tools that BEFSCI compiled are listed below, under the environmental and socio-economic dimensions they address. The intended "primary users" (i.e. governments and/or operators) and the "type" (i.e. planning and/or monitoring) are indicated in brackets.

BOX 2. FOOD SECURITY AND ITS FOUR DIMENSIONS: QUICK DEFINITIONS[1]

FOOD SECURITY: "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (World Food Summit, 1996).

- Food security comprises four dimensions: availability, access, utilization and stability.
- Food availability: "The availability of sufficient quantities of food of appropriate quality, supplied through domestic production or imports […]" (FAO, 2006).
- Food access: "Access by individuals to adequate resources (entitlements) for acquiring appropriate foods for a nutritious diet […]" (FAO, 2006).
- Food utilization: "Utilization of food through adequate diet, clean water, sanitation and health care to reach a state of nutritional well-being where all physiological needs are met […]" (FAO, 2006).
- Food stability: "To be food secure, a population, household or individual must have access to adequate food at all times. They should not risk losing access to food as a consequence of sudden shocks (e.g. an economic or climatic crisis) or cyclical events (e.g. seasonal food insecurity) […]" (FAO, 2006).

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1 The full definitions can be found here: www.fao.org/bioenergy/foodsecurity/befsci/definitions

TOOLS AND METHODOLOGIES

ENVIRONMENTAL

	Primary Users		Type	
	Governments	Operators	Planning	Monitoring
BIODIVERSITY (INCLUDING AGROBIODIVERSITY)				
Integrated Biodiversity Assessment Tool (**IBAT**)	✓	✓	✓	
Rapid Agrobiodiversity Appraisal (**RABA**) in the Context of Environmental Services Rewards	✓	✓	✓	✓
Rapid Assessment Program (**RAP**)	✓	✓	✓	✓
SOIL QUALITY				
CQESTR Model		✓		✓
LADA: Manual for Local Level Assessment of Land Degradation and Sustainable Land Management		✓	✓	✓
Revised Universal Soil Loss Equation (**RUSLE**)	✓	✓	✓	✓
WATER AVAILABILITY AND QUALITY				
AQUACROP	✓	✓	✓	
CROPWAT	✓	✓	✓	✓
Soil and Water Assessment Tool (**SWAT**)	✓	✓	✓	✓
Water Evaluation and Planning (**WEAP**)	✓		✓	
WOODY BIOMASS AND RESIDUES				
Woodfuel Integrated Supply/Demand Overview Mapping (**WISDOM**)	✓		✓	✓
GREENHOUSE GAS EMISSIONS				
EX-ACT (Ex Ante Carbon-Balance Tool)		✓	✓	
GHGenius	✓	✓	✓	✓
Global Emissions Model for Integrated Systems (**GEMIS**)	✓	✓	✓	✓
Resources and Energy Analysis Programme (**REAP**)	✓	✓	✓	✓
SimaPro	✓	✓	✓	✓
The Greenhouse Gases, Regulated Emissions, and Energy Use in Transport Model (**GREET**)	✓		✓	✓
CROSS-CUTTING				
Land Suitability Assessment	✓		✓	✓

SOCIO-ECONOMIC

	Primary Users		Type	
	Governments	Operators	Planning	Monitoring
LOCAL FOOD SECURITY				
Household Welfare Impact Analysis	✓		✓	✓
Integrated Food Security Phase Classification (**IPC**)	✓		✓	✓
Operator Level Food Security Assessment Tool	✓	✓	✓	✓
COMMUNITY DEVELOPMENT				
Human Development Index (**HDI**)	✓	✓	✓	✓
ENERGY SECURITY AND LOCAL ACCESS TO ENERGY				
Energy Development Index (**EDI**)	✓		✓	✓
Herfindahl-Hirschman Index	✓		✓	✓
GENDER EQUITY				
Gender-Related Development Index (**GDI**)	✓	✓	✓	✓
CROSS-CUTTING (including employment, wages, income and smallholders inclusion)				
BEFS - Computable General Equilibrium (**CGE**) Modelling of Economy-Wide Impacts of Bioenergy Development	✓		✓	✓
Biomass Socio-Economic Multiplier (**BIOSEM**)	✓	✓	✓	
Global Trade Analysis Project (**GTAP**) Model and Database	✓		✓	
Partial Equilibrium (**PE**) Models: AGLINK-COSIMO and OECD/FAO Agricultural Outlook	✓		✓	
Process Engineering for Environmental and Techno-economic Analysis (**PENTA**); Bioenergy Techno-economic Analysis for Africa (**BIOTA**)	✓	✓	✓	✓

For each of the aforementioned environmental and socio-economic dimensions, an introductory text about its relevance for food security and how it may be impacted by modern bioenergy development is included.

For each tool and methodology listed under these dimensions, a description is provided, followed by an example of its application. In the selection of these examples, priority was given to applications in the context of bioenergy and, secondarily, in the agricultural and energy sectors.

PART ONE:
ENVIRONMENTAL DIMENSIONS

1 BIODIVERSITY

INCLUDING AGROBIODIVERSITY

BIOENERGY, BIODIVERSITY (INCLUDING AGROBIODIVERSITY), AND FOOD SECURITY

Ecosystems provide a broad range of resources and services (often referred to as "ecosystem services") that are essential for food security, especially for food availability and utilization. In particular, ecosystems "supply food, [fuels] and drinking water, maintain a stock of continuously evolving genetic resources, preserve and regenerate soils, fix nitrogen and carbon, recycle nutrients, control floods, filter pollutants, [and] pollinate crops" (FAO, 2007, page 32). The long-term conservation of biodiversity and of the associated ecosystem services is key to food stability.

Agrobiodiversity, which is an important subset of biodiversity, may be defined as the variety of plants and animals – including crops, livestock, forestry and fisheries – used directly or indirectly for food, feed, fibre, fuels and pharmaceuticals (FAO, 19993). A high degree of agrobiodiversity may make farming systems more stable, robust and sustainable. This may contribute to the resilience of rural livelihoods to both biophysical and socio-economic shocks, such as pathogen infestations, changing weather patterns, and fluctuations in the price of crops and/or of agricultural inputs, with positive effects on the long-term stability of food supplies. Agrobiodiversity is also linked to dietary diversity4, i.e. to the availability of – and access to – an adequate variety of foods.

If not properly planned and managed, the expansion of bioenergy production may trigger both direct and indirect land-use changes, potentially leading to the loss or deterioration of certain ecosystems and of the resources and the services that such systems provide. This may have negative repercussions on food security.

In addition, the establishment of large-scale monocultures for bioenergy production may affect local agrobiodiversity - i.e. the variety of crops, livestock, forestry and fisheries used for food, feed, fibre, fuels and pharmaceuticals – and the traditional knowledge associated with the production and use of these plants and animals.

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2 FAO. 2007. *The State of Food and Agriculture – Paying Farmers for Environmental Services*. Rome: Food and Agriculture Organization of the United Nations (FAO).

3 FAO. 1999a. *Agricultural Biodiversity*, Multifunctional Character of Agriculture and Land Conference, Background Paper 1. Maastricht, Netherlands. September 1999.

4 Dietary diversity is an important socio-economic parameter and a key dimension of food utilization. Studies have shown that an increase in dietary diversity is associated with socio-economic status and household food security.

Further, the introduction of invasive alien species for bioenergy production may have repercussions on local plants and animals, including those used directly or indirectly for food, feed, fibre, fuels and pharmaceuticals.

Three tools were selected to assess (both *ex-ante* and *ex-post*) some of the impacts of modern bioenergy on biodiversity and agrobiodiversity discussed above, and to inform the development of a bioenergy sector and of operations that safeguard biodiversity. These tools are listed below. For each of them, the intended primary user(s) – i.e. governments and/or operators – and the type – i.e. planning and/or monitoring – are specified in brackets:

- **Integrated Biodiversity Assessment Tool (IBAT)** (Governments/Operators; Planning)
- **Rapid Agrobiodiversity Appraisal (RABA)** in the Context of Environmental Services Rewards (Governments/Operators; Planning/Monitoring)
- **Rapid Assessment Program (RAP)** (Governments/Operators; Planning/Monitoring)

1.1 Integrated Biodiversity Assessment Tool[5] (IBAT)

Author	Bird Life International; Conservation International; and United Nations Environment Programme, World Conservation Monitoring Centre (UNEP WCMC)
Year	2009
Type	Planning
Application level/scale	Regional; National; Farm
Primary users	Governments; Operators
Availability	Subscription fee
www.ibatforbusiness.org	

OVERVIEW

The Integrated Biodiversity Assessment Tool (IBAT) is a Web-based consolidated database of information on high priority sites for conservation and biodiversity protection.

SCOPE

IBAT covers marine, plant, and animal biodiversity and aggregates data from a range of sources. Biodiversity is the only indicator covered under the tool. IBAT seeks to inform project developers and policy-makers on key biodiversity areas to exclude from project development, and to provide baseline data on such areas for further impact assessment and monitoring. The user only needs to enter the coordinates and size of the proposed operation in order to receive results on the biodiversity areas within the project area or nearby.

AIMS AND OBJECTIVES

IBAT aims to facilitate access to information on high priority sites for conservation – namely protected areas and key biodiversity areas – to inform the implementation of corporate biodiversity policies and enhance environmental management systems. By incorporating IBAT into project planning, the aim is to reduce impacts on biodiversity.

METHODOLOGY AND REQUIRED DATA AND SKILLS

Data is aggregated on conservation areas including legally protected sites such as: nationally designated parks; reserves; indigenous and communal areas or other sites that have been assigned a protected status by a national government, and sites included under international agreements such as Ramsar, UNESCO, UNESCO Man-and-Biosphere Programme, World Heritage Conventions.

Data on "globally important sites for biodiversity", or Key Biodiversity Areas, are also included and drawn from IUCN's Best Practice Protected Areas Guidelines[6]. Sites are included and considered "globally important" if they are known to hold one or

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5 The information included in this section (excluding the example) was either excerpted or adapted from the IBAT web-site: www.ibatforbusiness.org

6 http://www.iucn.org/about/union/commissions/wcpa/wcpa_puball/wcpa_bpg/

more globally threatened species, endemic species, globally significant concentrations or populations, significant examples of biological communities or any combination of these features.

No specific skills are necessary in order to use this tool, which simply requires the users to input the latitude, longitude and size of the project.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

Data is limited by what governments are willing to allow access to and by the datasets currently available to the four partner organizations. IBAT is targeted at private sector/businesses and charges fees for use ranging from US$350–US$25 000 depending on the size of the company/business.

EXAMPLE: USE OF IBAT IN HIGH CONSERVATION VALUES (HCV) AREAS[7]

Researchers from ProForest and Conservation International, in collaboration with the High Conservation Values (HCV) Technical Panel, developed guidance on how to use IBAT in supporting assessments of HCV areas, focusing mainly on private firms as major clients, at both landscape and site scale.

The main data required for the aggregation of the IBAT datasets consists of: (1) World Database on Protected Areas[8] (WDPA); (2) Key Biodiversity Areas[9] (KBAs); (3) IUCN Red List of Threatened Species[10]; and (4) broad-scale conservation priorities[11] (including Biodiversity Hotspots, Endemic Bird Areas, High Biodiversity Wilderness Areas). As for the HCV areas, management areas vary between ca. 10–106 ha, while assessments are aimed at a variety of different product certifications (for example, timber, pulp, palm oil and diverse natural resources).

As highlighted in the guidance, IBAT can be considered as an efficient first step in providing information on protected areas and KBAs, which are useful for HCV assessments. This tool, however, does not present users with all the data needed for a comprehensive HCV assessment. A further limitation is represented by the use of large scale parameters for the definition of special distribution of natural habitats and land use patterns. Consequently, commercial entities might need assistance from conservation NGOs and governments to manage information on the latter.

Considering main findings and limitations above, authors suggest that the IBAT is not to be considered as a "one stop shop" but rather as a "first stop shop" in assessing HCVs. Follow-up activities might comprise the inclusion of additional national and local information, field assessments, and expert reviews.

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7 The information included in this section was excerpted and adapted from IBAT's web-site: https://www.ibatforbusiness.org/kbas_and_hcvs

8 http://www.wdpa.org/

9 https://www.ibatforbusiness.org/kbas

10 http://www.iucnredlist.org/

11 http://www.biodiversitya-z.org/pages/15

1.2 Rapid Agrobiodiversity Appraisal (RABA) in the Context of Environmental Services Rewards[12]

Author	**Kuncoro, S. A, Noordwijk, M.V., Martini, E., Saipothing, P., Areskoug, V., Putra, A.E., O'Connor, T.**
Year	2006
Type	Planning; Monitoring
Application level/scale	Local; Farm
Primary users	Governments; Operators
Availability	Free
www.ibcperu.org/doc/isis/8307.pdf	

OVERVIEW

The Rapid Agrobiodiversity Appraisal (RABA) was developed under the assumption that effective natural resources management, including biodiversity conservation, can only be achieved if there is a synergy between three different types of capital – human, natural, and social. The combination of all three provides the basis for evaluation of local agrobiodiversity for conservation. In RABA, local perspectives on agricultural areas are used to define threats, values (with regards to biodiversity), and potential development of rewards for agrobiodiversity conservation. RABA uses secondary data to rapidly assess facets of biodiversity, rapid rural appraisal, and semistructured interviews to obtain local perspectives.

SCOPE

RABA is not a technical biodiversity appraisal. It is understood that the diversity of a place means that every locality is "unique" in its own way and there is thus no universal "how to" method that prescribes a rigid appraisal. Rather it is a suggested approach to use when it is necessary to collect information rapidly about the potential of an agricultural landscape to conserve biodiversity while maintaining productivity.

The method is intended to be an iterative, stepwise approach, suggesting that the user can update new information and modify the approach to suit different localities. If a first screening suggests that there is little opportunity for successful negotiations of "rewards for biodiversity conservation", the process can stop there. If the first indication is positive, a more detailed assessment can clarify the strength of the case or reveal the pitfalls that have to be avoided. RABA has four stages for sellers and buyers to engage in arranging environmental-service rewards (ESR); namely scoping, identifying potential partners,

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12 The information included in this section was either excerpted or adapted from: Kuncoro, S. A, Noordwijk, M.V., Martini, E., Saipothing, P., Areskoug, V., Putra, A.E., O'Connor, T. 2006. *Rapid Agrobiodiversity Appraisal (RABA) in the Context of Environmental Services Rewards: Protocols for Data Collection and Case Studies in Rubber Agroforests in Bungo District, Jambi, Indonesia and Fragmented Forest in North Thailand*. Situ Gede, Indonesia: World Agroforestry Centre, ICRAF Southeast Asia Regional Office.

negotiating agreements, and monitoring and evaluating compliance and outcomes.

RABA is not a stand-alone tool; rather it is a tool in which approaches to rapidly collect data and appraise the conservation value of an area are combined, summarized and adapted. Different techniques such as Rapid Rural Appraisal[13], Stakeholder Analysis[14] and exploration of "citizen science" (such as Local Ecological Knowledge[15]) are among the methods or approaches that have been taken into account in the different phases of RABA.

AIMS AND OBJECTIVES

The goal of RABA is to identify opportunities for economic development through agriculture which also achieve conservation and preservation of biodiversity. The RABA method aims to develop and test a tool for matching a "bottom-up" sellers' perspective and a "top-down" buyers' view on strategies that are cost-effective.

METHODOLOGY AND REQUIRED DATA AND SKILLS

The appraisal relies primarily on publicly available secondary data on biodiversity and conservation hotspots, and then combines that with 'first hand' data obtained through interviews with local stakeholders. RABA has been developed for use in a developing country context and is an easy to follow approach. A basic understanding of conservation, species, and interviewing skills would be an asset in conducting the appraisal and interpreting results.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

RABA is highly dependent on the availability of secondary data. In areas where there may not be high quality or readily available secondary data, the timeframe and costs of using the method would increase greatly. The flexibility of the approach is ideal for meeting local conditions and priorities, but may also make it difficult to aggregate results and requires that there is at least one person familiar with the methods to adapt the approach to the local scenario. RABA could be used for bioenergy projects as a way to quickly assess the potential and/or realized impact on biodiversity from a given operation or in a given area.

EXAMPLE: RABA APPLICATION TO RUBBER AGROFOREST IN INDONESIA AND FRAGMENTED FOREST IN THAILAND

RABA was tested by the World Agroforestry Centre (ICRAF) in two sites in 2005: Bungo District (Jambi, Indonesia) and Northern Thailand.

RABA was developed through different phases, involving different actors within the process. The initial basis for the Appraisal was defined by a team of experts from different

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13 For an overview, see: http://www.iisd.org/casl/caslguide/rapidruralappraisal.htm

14 For an example, see: http://www1.worldbank.org/publicsector/anticorrupt/PoliticalEconomy/PDFVersion.pdf

15 For an example, see: Chamley, S., Fischer, A.P., Jones, E.T. "Traditional and Local Ecologic Knowledge About Forest Biodiversity in the Pacific Northwest". *General Technical Report 751*, April 2008. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

conservation agencies (Conservation International and WWF), a research centre (ICRAF), and local NGOs[16], together with representatives from the local community in the town of Muara Bungo (Bungo district, Jambi, Indonesia) in August 2004. The outcomes were validated during subsequent meetings in 2004, including at the Fourth IUCN World Conservation Conference in Bangkok in November 2004.

The overall objective of the RABA in these two examples was to obtain initial data necessary for sellers, intermediaries and buyers to explore the potential for the development of conservation reward systems in the two targeted sites, as well as offering guidance on advocacy for conservation of agrobiodiversity in the context of environmental science rewards. In particular, the following specific objectives were pursued: (1) locate potential conservation sites and determine their conservation values; (2) land use identification and classification; (3) analysis of threats and opportunity through secondary data; (4) stakeholder analysis, and (5) understanding of potential future scenarios.

The main finding of the appraisals in both Bungo and North Thailand was that the application of the RABA provided sufficient evidence on the sites' potential for agrobiodiversity conservation, as well as the information to proceed with the development of a reward mechanism.

Given the importance of secondary data analysis in the RABA, the main challenge encountered was the lack of information in specific areas/subjects of enquiry that might have contributed to building stronger overall conclusions for the Appraisal.

The main lesson learned from the application of the tool in Bungo, Indonesia, and North Thailand is that some parts of RABA can be used as a basis for further and more detailed studies. Additional analysis employing the Multidisciplinary Landscape Assessment[17] (MLA) approach and the Rapid Assessment Program[18] (RAP) method might be used to confirm whether the land use and sites can actually fulfil the expected conservation functions.

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16 Komunitas Konservasi Indonesia Forum Komunikasi dan Konservasi [KKI-WARSI] and Yayasan Gita Buana

17 For an overview of MLA, see: ftp://ftp.cgiar.org/CIFOR/LPFWorkshop/Attachment/App9.1MLA.pdf

18 For an overview of RAP, see: https://learning.conservation.org/biosurvey/RAP/Toolkit/Pages/default.aspx#

1.3 Rapid Assessment Program[19] (RAP)

Author	Conservation International
Year	1990
Type	Planning; Monitoring
Application level/scale	Local; Farm
Primary users	Governments; Operators
Availability	Free
https://learning.conservation.org/biosurvey/RAP/Pages/default.aspx#	

OVERVIEW

Conservation International's Rapid Assessment Program (RAP) was created in 1990 to address the lack of biological information needed to make quick but sound conservation decisions. RAP deploys teams of international and host-country expert scientists to conduct rapid first-cut assessments of the biological value of selected areas. RAP surveys generally take a minimum of four days and, in most cases, a maximum of six weeks. Preliminary results are made available immediately to local and international decision-makers through reports and on the Internet. RAP data is then analysed in tandem with social, economic, and other ecosystem information to develop a comprehensive conservation strategy. RAP surveys are not intensive and do not record all species in an area; they target taxonomic groups and sites that will provide key information needed for conservation such as the presence of threatened and endemic species, habitat condition, and threats to documented species.

SCOPE

The three types of RAP surveys include Terrestrial, Freshwater and Marine. Terrestrial RAP assesses the biological diversity of poorly known terrestrial ecosystems about which information is needed to take conservation action. RAP scientists gather and report data about vegetation, birds, mammals, reptiles, amphibians, and select insect groups. Freshwater RAP (AquaRAP) provides a first assessment of the biological value of freshwater aquatic ecosystems in order to identify priorities and opportunities for conservation. Expert teams of scientists survey fish, plants, invertebrates, water quality, amphibians and reptiles. Marine RAP surveys generate information on coastal and near-shore shallow-water marine habitats.

The typical time frame for CI's Rapid Assessment Program (RAP) is: Field survey of 4-6 weeks, with 5-7 days surveying per site; Preliminary report published within 2 months of field survey; Final report (with species lists) published about one year after field survey.

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[19] The information included in this section (excluding the example) was either excerpted or adapted from Conservation International's RAP web-site: https://learning.conservation.org/biosurvey/RAP/Pages/default.aspx#

AIMS AND OBJECTIVES

The objective of RAP is to provide information needed to plan, design, implement and publish biodiversity information in order to promote biodiversity surveys around the world. RAP seeks to build local capacity for rapid biodiversity assessments by providing the resources and tools for scientists around the world to assess and identify the principal species for conservation and action.

METHODOLOGY AND REQUIRED DATA AND SKILLS

In general, rapid biodiversity assessment involves conducting a survey or inventory of the species of an area. The assessment could focus on one taxonomic group, such as birds or plants. A multi-taxa terrestrial assessment would survey more than one taxonomic group, most typically: plants, mammals, birds, reptiles, amphibians, and select invertebrate groups such as ants, butterflies, dragonflies, orthoptera, beetles, and land crabs. In addition to the species list, scientists doing a survey can also collect information on habitat condition, disturbances, and the biology of the species they are surveying.

The RAP surveys are only done by scientists and most often by a combination of Conservation International scientists and local scientists. Taxonomic experts are involved in RAP surveys in order to best sample and identify the species. RAP surveys include both international and local expert scientists as appropriate, and involve students and local community members as trainees as much as possible.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

Although a 'rapid' biodiversity assessment, RAP still requires at least a few months to produce a final report.

RAP could be used to identify potential biodiversity concerns for bioenergy projects planned in specific regions/areas but would not provide information specifically on the potential threat of biofuels to biodiversity.

EXAMPLE: A RAPID BIOLOGICAL ASSESSMENT OF LOKUTU, DEMOCRATIC REPUBLIC OF CONGO, BASED ON RAP[20]

RAP was used in a study by Conservation International (CI) in the Democratic Republic of Congo (DRC), within a project aimed at the conservation and development of the Lokutu Region, within the Territory of Basoko, in the Congo River Basin.

Specifically, the scientific expedition consisted of a mixed team of scientists (biologists, zoologists, and natural scientists), whose assignment was funded as part of a grant from the United States Agency for International Development (USAID) to Conservation International.

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20 The information included in this section was excerpted and adapted from: Butynski, T.M., Mc Cullough, J. (eds.). 2007. "A Rapid Biological Assessment of Lokutu, Democratic Republic of Congo". *RAP Bulletin of Biological Assessment 46*. Arlington, VA (USA): Conservation International.

The objective of the RAP was to study the conservation value of the Lokutu area. The Assessment acted as a follow-up to an initial survey (carried out in 2002) of the area around the village of Lokutu, exploring opportunities for CI involvement in the local logging and oil palm concession of Unilever. The overall aim of the assessment was to identify potential opportunities for long-term investment within High Biodiversity Wilderness -Conservation International's biodiversity conservation programme for the Congo Basin. Specifically, the RAP aimed at providing: (1) an overview of species diversity; (2) an assessment of the potential threats to biodiversity in Lokutu; (3) recommendations on conservation priorities; and (4) to promote the conservation of the ecosystem by making the RAP results internationally available.

The RAP team examined selected taxonomic groups within the following: plants, odonates (dragonflies), amphibians, reptiles, birds and larger mammals (with an emphasis on primates). The taxonomic varieties were chosen to determine the biological diversity of the Lokutu Region, and the degree of endemism of the ecosystem.

Researchers were not granted access to the forest areas outside the Unilever plantation, thus limiting the assessment. This highlights the importance of liaising with local authorities and stakeholders in order to get access to all the relevant areas prior to the assessment.

In terms of biological conservation, the main finding of the assessment was the overall loss of biodiversity and other conservation values in the Lokuto area. As a result of the RAP, the ecosystem was not recommended as part of CI's Congo Basin High Biodiversity Wilderness Area. Moreover, the following additional issues were identified: (1) the ever increasing human population and the associated need to exploit the area's natural resources; (2) the lack of interest/will/ability of both central and local governments to control and manage the use of natural resources; and (3) and the high costs (both in financial terms and time) of carrying out the analysis in the Lokuto area.

2 SOIL QUALITY

BIOENERGY, SOIL QUALITY, AND FOOD SECURITY

Soil quality is a key element of the productive capacity of land, which determines, all else equal, the amount of agricultural output that can be obtained from a given amount of land. Therefore, soil quality is a key factor in food production/availability, and its long-term maintenance is also important for the stability of food supply.

If good soil management practices are not implemented by operators, bioenergy feedstock production may contribute to soil degradation, for instance through: soil compaction, soil erosion, loss of soil organic matter, loss of plant nutrients and soil salinization.

Part of the aforementioned effects can result from an excessive removal from the soil of primary agricultural and forestry residues used as modern bioenergy feedstocks. Residues play an important role in soil management, both as soil cover and as agricultural fertilizers (i.e. green manure).

If bioenergy feedstock production contributes to soil degradation, there may be a reduction in the degree of suitability of some areas for certain crops, including staple crops, with negative repercussions on food security.

At the same time, however, dedicated bioenergy crops/feedstocks may be grown on contaminated and degraded lands and contribute to restore soil quality through the implementation of specific good practices, with positive effects on the future productive capacity of these lands.

Three tools were selected to assess (both ex-ante and ex-post) some of the impacts of modern bioenergy on soil quality discussed above, and to inform the development of a bioenergy sector and of operations that safeguard soil quality. These tools are listed below. For each of them, the intended primary user(s) – i.e. governments and/or operators – and the type – i.e. planning and/or monitoring – are specified in brackets:

■ **CQESTR Model** (Operators; Monitoring)
■ **LADA: Manual for Local Level Assessment of Land Degradation and Sustainable Land Management** (Operators; Planning/Monitoring)
■ **Revised Universal Soil Loss Equation (RUSLE)** (Governments/Operators; Planning/ Monitoring)

2.1 CQESTR Model[21]

Author	United States Department of Agriculture (USDA)
Year	2008
Type	Monitoring
Application level/scale	Local; Farm
Primary users	Operators
Availability	Free
www.ars.usda.gov/Main/docs.htm?docid=13499	

OVERVIEW

The CQESTR Model (version 2.0) is a process-based soil carbon balance model that computes biological decomposition rates of crop residues or organic amendments as they convert to soil organic matter (SOM) or soil organic carbon (SOC).

SCOPE

The model is used for the field scale evaluation of SOC stocks. The model operates on a daily time-step and performs long-term (100-yr) simulations. The carbon pools are depicted as a *continuum*. The organic material decomposition is a three phase process. After each residue placement in the soil, decomposition occurs in two phases. Phase I is a rapid phase covering the first 1 000 cumulative degree-days (CDD or thermal time), approximating the oxidation of readily metabolizable substrate. Phase II is a slow decomposition phase, representing oxidization of more recalcitrant materials. Crop residues and organic amendments are categorized by their placement in the soil and their identities are maintained during the two phase decomposition. Each organic residue addition is tracked separately according to its placement within distinct soil horizons. 15 000 CDD after the completion of Phase II, the composted residue is transferred to the stable SOM pool (Phase III).

AIMS AND OBJECTIVES

The CQESTR Model was developed to evaluate the effects of agricultural management practices on short and long-term soil organic matter and soil organic carbon dynamics.

METHODOLOGY AND REQUIRED DATA AND SKILLS

The CQESTR Model uses readily available input data at the field scale. Data inputs include weather, above-ground and below-ground biomass additions, N content of residues and amendments, soil properties, and management factors such as tillage and crop rotation. Crop rotation, annual yields, and tillage information are organized in crop management

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21 The information included in this section (excluding the example) was either excerpted or adapted from: http://www.ars.usda.gov/Main/docs.htm?docid=13499

files associated with the c-factor of the Revised Universal Soil Loss Equation (RUSLE, version 1). These consist of crop grain yields, shoot-to-grain ratios, dates of all operations (e.g. tillage, seeding, harvest, biomass addition, biomass removal, etc.), depth of tillage and the fraction of the soil surface covered, and effects of tillage on residue (e.g. fraction of pre-tillage residue weight remaining on the soil surface after each tillage). Crop rotation, grain and residue, residue removal and tillage information are required explicitly.

The use of CQESTR requires knowledge of natural sciences and soil management practices.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

Residue consumption by macro-fauna, deposition or loss of SOC at the soil surface, or the physical transfer between soil layers, are not accounted for in the CQESTR model.

CQESTR could be applied to bioenergy, specifically to assess the impacts on soil quality of the removal of primary agricultural residues and their use for bioenergy production. The main limitations of the CQESTR model depend on the availability and input of data to accurately reflect the soil management practices. The other primary limitation of CQESTR is in relation to scale. The model was developed primarily for research purposes and not for analysing problems in large-scale ecosystems. The simplicity and accessibility of the model sacrifices the refinement of the model for large-scale use.

EXAMPLE: APPLYING THE CQESTR MODEL TO TROPICAL SOILS IN BRAZIL[22]

Although the CQESTR model was initially developed for use in the US only, the US Agency for International Development (USAID) and the US Department of Agriculture (USDA) sponsored a study to test its performance outside of temperate soils, and specifically in tropical areas. Data on CQESTR was collected and analysed by a team of Agronomists and Soil Scientists.

The specific objective of the study was to evaluate CQESTR's performance in simulating organic carbon dynamics in tropical Brazilian soils, under two types of harvesting systems: (1) no-tillage and (2) plowed systems. The study was carried out in two regions, the Minas Gerais (Coimbra) and Piauí State (Baixa Grande do Ribeiro - BGR). Cultivation systems in both regions included no tillage, reduced tillage (one disc of chisel plow and one harrow leveling or one heavy disc harrow and one harrow leveling) and conventional tillage (two heavy disc harrows associated with one disc plow and two harrow leveling or heavy disk harrowings).

Some changes in the CQESTR source code were necessary to account for specific geographical areas and management practices within the areas selected for the study.

Overall, the CQESTR Model showed acceptable performance to predict SOC dynamic

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22 The information included in this section was excerpted and adapted from: Leite, L.F.C., Doraiswamy, P.C., Causarano, H.J., Gollany, H.T., Milak, S., Mendonca, E.S. 2009. "Modeling organic carbon dynamics under no-tillage and plowed systems in tropical soils of Brazil using CQESTR". *Soil & Tillage Research* 102: 118–125.

in two tropical soils of Brazil. However, the model simulations in general underestimated SOC stock at two study sites in Brazil, especially under no-tillage system. The conversion from native forest to croplands greatly reduced the SOC stocks irrespective of the tillage practices. Crop residue was a major factor in maintaining or reducing the loss of SOC. More research is needed to evaluate the CQESTR model's performance for simulating SOC dynamics in tropical soils. Further adjustments, such as inclusion of clay mineralogy and organic matter interaction, might be necessary to improve the model's estimates.

2.2 LADA: Manual for Local Level Assessment of Land Degradation and Sustainable Land Management[23]

Author	Food and Agriculture Organization of the United Nations (FAO)
Year	2004
Type	Planning; Monitoring
Application level/scale	Local; Farm
Primary users	Operators
Availability	Free
www.fao.org/nr/lada	

OVERVIEW

The Land Degradation Assessment in Drylands (LADA) project developed a package of tools and methods to assess and quantify land degradation in dryland areas. The VS-Fast methodology describes and evaluates the morphological conditions of soils in the field. This is a more rapid and immediate method of soil assessment than the conventional sets of soil physical measurements commonly used.

SCOPE

The methodology includes detailed methods to collect and 'score' data beginning with site selection and description, and concluding with describing and measuring the soil. Soil description includes checking for depth, structure, texture, colour, earthworms, roots, and supplying a photo. Emphasis with VS-Fast is on the assessment, both qualified and quantified, of soil physical condition (soil structure units and porosity) as well as soil colour, root development, soil fauna, slaking and dispersion, pH, soil and water salinity, organic matter status and water infiltration.

AIMS AND OBJECTIVES

The methodology is designed for farmers (and their advisers) to use with the principal aim of providing an affordable and user-friendly way to assess land degradation by farmers in poor/developing countries. VS-Fast aims to be both simple and scientifically robust so as to maximize farmers' ability to apply the techniques of soil assessment. The VS-Fast system aims to capture the condition and trends, and extent and ramifications of soil degradation, and organic matter and soil biota decline (both natural/inherent and anthropogenic) in cropping, grazing and woodlands, worldwide.

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23 The information included in this section (excluding the example) was either excerpted or adapted from: FAO. 2011. Land Degradation Assessment in Drylands: *Manual for Local Level Assessment of Land Degradation and Sustainable Land Management – Part 1*: Planning and Methodological Approach, Analysis and Reporting; and Part 2: Field Methodology and Tools.

METHODOLOGY AND REQUIRED DATA AND SKILLS

Designed for use by farmers, the skill set required is very low. The methodology also includes a detailed step-by-step approach to collecting data. All data can be collected at the site level and then 'scored' based on a range of peer reviewed literature and studies on best practices and comparative data. The measures are designed to be reproducible and quickly learned. The methodology requires the user to enter a score - (0) poor, (1) moderate or (2) good[24] - based on a visual assessment of the following features: soil texture; soil structure; soil porosity; number and colour of soil mottles; soil colour; earthworms; soil smell; rooting depth; surface ponding; surface cover; surface crusting; and soil erosion from wind and water. Because some soil indicators are relatively more important in the assessment of soil quality than others, the methodology provides a weighting factor of 1, 2 and 3. The total of the VS rankings gives the overall Soil Quality Index score for the sample being evaluated. If this score is less than 20, the soil is rated as "poor"; with a score between 20 and 37, it is rated as "moderate", while with a score greater than 37, the rating is "good".

A number of tools are required in order to perform a visual soil assessment. The standard toolkit comprises:

- a spade – to dig a soil pit and to take a 200 mm cube of soil for the drop shatter soil structure test;
- a plastic basin (about 450 mm long x 350 mm wide x 250 mm deep) – to contain the soil during the drop shatter test;
- a hard square board (about 260x260x20 mm) – to fit in the bottom of the plastic basin on to which the soil cube is dropped for the shatter test;
- a heavy-duty plastic bag (about 750x 500 mm) – on which to spread the soil, after the drop shatter test has been carried out;
- a knife (preferably 200 mm long) to investigate the soil pit and potential rooting depth;
- a water bottle – to assess the field soil textural class;
- a tape measure – to measure the potential rooting depth;
- a field guide – to make the photographic comparisons; and
- a pad of scorecards – to record the VS for each indicator.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

Although designed for farmers, some of the language in the methods is still at a technical level that may be outside the understanding of some farmers. However, the methodology does explain each term. The main limitations of the methodology are that due to the basic tools suggested for use, the methodology in practice will only capture data from the top 40-50 centimetres of soil. Another limitation is the granularity of data that can be captured and analysed in the field. For more detailed analysis, the use of a laboratory or more sophisticated instruments would be required.

VS-Fast could be used to assess soil physical conditions in existing or potential

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24 Intermediate scores – i.e. 0.5 and 1.5 – may be used as well.

bioenergy feedstock production areas, but would benefit from use in combination with other tools and methodologies, for example that address water use and requirements.

EXAMPLE: VS-FAST USE IN LAND DEGRADATION ASSESSMENT (LADA) PROJECT, SENEGAL[25]

The VS-Fast methodology was applied in Senegal by the Centre for World Food Studies of the VU University Amsterdam (SOW-VU) in 2009, while supporting FAO analysis on land degradation assessment under the GEF-funded Land Degradation Assessment in Dryland Areas (LADA) project. The use of VS-Fast aimed at providing a set of (1) visual indicators (i.e. texture, structure, occurrence of soil crusts, presence of earthworms or other pertinent soil fauna, root conditions) and (2) measurable parameters (i.e. slaking and dispersion, soil pH, water infiltration, organic carbon, soil salinity) to produce a weighted overall scoring of soil quality in Senegal.

VS-Fast methodology assigned to each soil in the sampled sites (three Geographic Assessment Areas, GAA, were selected) three potential qualitative categories of land quality, namely: (1) 'degraded'; (2) 'normal'; and (3) 'good'. More specifically, 'normal' indicates regular and conventional land management systems, while 'good' refers to natural unaffected land where SLM has been practiced. Similarly, based on household survey responses, the study categorized the quality of natural resources for cultivated land, rangeland, forest and water in each GAA as 'low', 'moderate' or 'high'.

Main results confirm that, by comparing VS-Fast scores with GAA, there exists a tendency for 'degraded' sites to be associated with low VS-Fast and 'good' land with high VS-Fast scores.

One of the main limitations of the study was the small number of sampled households (51) and soils (71). Hence, the results of the assessment were not representative of Senegalese farmers and land uses as a whole, and cannot serve as a basis for policy-making at national level. Larger samples should be used for such purposes.

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25 The information included in this section was excerpted and adapted from: Centre for World Food Studies of the VU University Amsterdam (SOW-VU). 2011. *Local land degradation assessment, soil conservation and nutrient balances in Senegal – Final report*. Prepared for the Land and Degradation Assessment in Dryland Areas (LADA) project.

2.3 Revised Universal Soil Loss Equation[26] (RUSLE)

Author	United States Department of Agriculture – Agricultural Research Service (USDA – ARS)
Year	1993
Type	Planning; Monitoring
Application level/scale	Local; Farm
Primary users	Governments; Operators
Availability	Free
www.ars.usda.gov/Research/docs.htm?docid=6010	

SHORT INTRO/OVERVIEW

The Revised Universal Soil Loss Equation (RUSLE) 2 can be applied to any land (including cropland) where mineral soil is exposed to the precipitation and/or where surface runoff generated by rainfall intensity is greater than the infiltration rate of water into the soil. RUSLE2 estimates rates of rill and interrill soil erosion[27] caused by rainfall and its associated overland flow. The rate of rill and interrill erosion is determined by four main factors: climate; soil; topography, and land use. RUSLE2 can be applied to a specific site by describing field conditions at the site for these four factors. This field description is then used to compute erosion estimates.

SCOPE

RUSLE2 can be applied to: cropland; rangeland; disturbed forestland; mined land; construction sites; reclaimed land; landfills; military training sites; parks, and any land where mineral soil is exposed to the direct force of water droplet impact and where the surface runoff generated by rainfall is greater than the infiltration rate of water into the soil.

AIMS AND OBJECTIVES

RUSLE2 was developed to enhance the RUSLE1 approach for estimating soil loss in a graphical user interface that can convert US and metric data units. RUSLE2 is primarily used by USDA field office officials for conservation planning.

METHODOLOGY AND REQUIRED DATA AND SKILLS

RUSLE2 is land use neutral, i.e. it can be applied to the wide range of land types listed above under Scope, and is based on equations that describe how features such as crop yield, vegetative canopy and rooting pattern, surface roughness, mechanical soil disturbance, amount of biomass on the soil surface and in the upper layer of soil, and related factors affect rill and interrill erosion. The major factors assessed by RUSLE2 to determine

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26 The information included in this section (excluding the example) was either excerpted or adapted from the USDA's RUSLE web-site: www.ars.usda.gov/Research/docs.htm?docid=6010

27 Rill and interrill erosion are the removal of layers from the land surface by the action of rainfall and runoff.

impacts on soil erosion are: climate (primarily rainfall and temperature); soil type; topography; land use, and land management practices such as tillage; buffer zones; runoff interceptors, and others. The RUSLE2 user selects information in the RUSLE2 database to describe these variables at a specific field site. The RUSLE2 user is not required to collect field data on these variables. The user is only required to input information on topography (i.e. slope length and steepness).

RUSLE2 tool is user-friendly although it does require the user to have at least a basic knowledge and understanding of agronomy, soil science, and land management.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

The main limitation of RUSLE2 is the reliance on default values, which may not always accurately reflect local conditions. RUSLE2 can be used in a variety of contexts, including in bioenergy operations.

EXAMPLE: TESTING THE SUITABILITY OF DIFFERENT EROSIVITY MODELS USED IN RUSLE2 IN KERALA, INDIA[28]

Researchers from the University of Cambridge (Department of Engineering) tested the suitability of RUSLE2 to build an iso-erosivity map of the South West Indian Region[29], while comparing the tool with potential alternative models.

The specific objective of the study was to test whether the RUSLE2 standard expression to calculate the rainfall-erosivity factor (R) could be substituted by alternative models.

The study took into consideration different equations used to calculate the kinetic energy of rainfall. Such equations relate to three main parameters defining rainfall erosivity, specifically: (1) rational, (2) local, and (3) geographical parameters. R calculations are based on varying rainfall intensity (expressed in mm/h) and the study screened 11 different expressions of the latter, developed from data collected in the United States (on which R calculations in RUSLE are based on), Australia, Hong Kong, Portugal, Spain and Zimbabwe.

The study concluded that for the analysis of erosion in the Kerala Region, the expressions used by Rosewell (1986, based on data gathered in Australia) and Carter et al. (1974, data gathered in the United States) are comparable to standard R calculations used in the RUSLE 2 model, (developed by Brown and Foster 1987) and therefore can be used as alternative model computations for erosivity modeling in South West India.

Although no specific follow-up work is suggested in the paper, since the analysis suggests that different R calculations can substitute standard RUSLE 2 functions, follow-up work might include the development of RUSLE through alternative and/or local equations.

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28 The information included in this section was excerpted and adapted from: Pal, I., Al-Tabbaa, A. "Suitability of different erosivity models used in RUSLE2 for the South West Indian region". Environmentalist (2009) 29: 405-410.

29 For further information on the iso-erosivity map of the South West Indian Region, see: Babu, R., Tejwani, K.G., Agarwal, M.C. 1978. "Distribution of erosion index and iso-erodent map of India". Indian Journal of Soil Conservation 6(1): 1–14.

3 WATER AVAILABILITY AND QUALITY

BIOENERGY, WATER AVAILABILITY AND QUALITY, AND FOOD SECURITY

Water resources affect several dimensions of food security. The availability and affordability of suitable water resources for agriculture is important for food production/availability. In addition, the availability and access to adequate supplies of safe drinking water are important for food preparation/utilization, as well as for human health and thus for a good biological utilization of the food consumed. Furthermore, the long-term availability of suitable water resources for agriculture is important for the future stability of food supplies as well.

Bioenergy feedstock production and processing may put pressure on water resources and compete with other uses, including both food production and preparation, potentially contributing to water stress/scarcity, with negative repercussions on food availability and utilization. If good practices are not adopted by operators, bioenergy feedstock production and processing may also have a negative impact on water quality, due mainly to fertilizer and pesticide leaching from feedstock production and to wastewater discharges from processing plants.

At the same time, however, bioenergy projects and operations may lead to investments in new or improved water facilities for both workers and local communities, with positive repercussions for their food security.

Four tools were selected to assess (both *ex-ante* and *ex-post*) some of the impacts of modern bioenergy on water availability and quality discussed above, and to inform the development of a bioenergy sector and of operations that safeguard water availability and quality. These tools are listed below. For each of them, the intended primary user(s) – i.e. governments and/or operators – and the type – i.e. planning and/or monitoring – are specified in brackets:

■ **AQUACROP** (Governments/Operators; Planning)
■ **CROPWAT** (Governments/Operators; Planning/Monitoring)
■ **Soil and Water Assessment Tool (SWAT)** (Governments/Operators; Planning/Monitoring)
■ **Water Evaluation and Planning (WEAP)** (Governments; Planning)

3.1 AquaCrop[30]

Author	Food and Agriculture Organization of the United Nations (FAO)
Year	2008
Type	Planning
Application level/scale	Local; Farm
Primary users	Governments; Operators
Availability	Free
www.fao.org/nr/water/aquacrop.html	

OVERVIEW

AquaCrop is the crop-model that has been developed by the Food and Agriculture Organization of the United Nations (FAO) to simulate yield responses of several herbaceous crops to water. It is designed to balance simplicity, accuracy and robustness, and is particularly suited to address conditions where water is a key limiting factor in crop production.

SCOPE

Similarly to many other crop-growth models, AquaCrop includes the following components: soil water balance; crop development, growth and yield; atmospheric and climatic conditions, e.g. thermal regime, rainfall, evaporative demand and carbon dioxide (CO_2) concentration; and crop management, including agronomic practices such as irrigation and fertilization. Simulation runs of AquaCrop are executed with daily time steps, using either calendar days or growing degree days[31].

AIMS AND OBJECTIVES

AquaCrop is mainly addressed to practitioners, consulting engineers, governmental agencies, NGOs and farmers associations. It aims to assist users with developing agricultural water management strategies by simulating yield response to water levels, specifically for irrigation management, project planning, and scenario simulations at different scales.

METHODOLOGY AND REQUIRED DATA AND SKILLS

AquaCrop treats herbaceous crops and tree crops separately. Only water management and yield estimations are provided for tree crops as they have additional complexities that are more difficult to simulate.

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30 The information included in this section (excluding the example) was either excerpted or adapted from the FAO's AquaCrop web-site: www.fao.org/nr/water/aquacrop.html
31 Growing degree days or growing degree units are a measure of heat accumulation to forecast plant and pest growth rates.

Root zone water content is simulated by keeping track of incoming and outgoing water fluxes at its boundaries, considering the soil as a water storage reservoir with different layers. Instead of a leaf area index, AquaCrop uses canopy ground cover. Canopy development, stomatal conductance, canopy senescence and the harvest index are the key physiological crop responses to water stress. Evapotranspiration is simulated as crop transpiration and soil evaporation and the daily transpiration is used to derive the daily biomass gain via the normalized biomass water productivity of the crop. The normalization is for reference evapotranspiration and CO_2 concentration to make the model applicable to diverse locations and seasons, including future climate scenarios. AquaCrop accommodates different water management systems, including rainfed agriculture and supplemental, deficit, and full irrigation. Simulations can be carried out both on calendar and thermal time, and the developing versions will incorporate effects of nutrient regimes, particularly nitrogen, and of soil salinity.

AquaCrop requires that users hold at least a university degree and have an understanding of agronomy in order to be able to use the model and interpret the data. While AquaCrop has been developed to be applied in a developing country context, the data require calibration and this calls for a sophisticated understanding of agronomy to ensure that it is done to deliver meaningful results.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

AquaCrop can be used for bioenergy crops/feedstocks (for maize, for instance, see the example in section two below[32]), although it does not include water requirements for the entire production cycle since it is only addressing crop yield responses to water. The main limitation of AquaCrop is that it only applies to the quantity of water required but does not include any reference or way to assess how the requirements intersect with the amount of water available in the area. Similarly, Aquacrop addresses the quantity of fertilizer application but not how it is applied.

EXAMPLE: PARAMETERIZATION AND TESTING OF AQUACROP FOR MAIZE[33]

Maize (*Zea mays L.*) was the first crop chosen to parameterize and test version 3 of FAO's AquaCrop model. A study was conducted to calibrate AquaCrop for maize in terms of conservative parameters and test how the model performs with these parameters held constant. The model was first parameterized and tested for maize with extensive data sets collected in different field experiments at Davis, (California, USA), then the preliminarily parameterized model was tested with data sets from Spain, Texas, and Florida, with the

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32 For the application of AquaCrop to another bioenergy feedstock, i.e. sunflower, see: Todorovic, M., Albrizio, R., Zivotic, L., Abi Saab, M., Stöckle, C., and Steduto, P. 2009. "Assessment of AquaCrop, CropSyst, and WOFOST Models in the Simulation of Sunflower Growth under Different Water Regimes". Agronomy Journal 101: 509–521.

33 The information included in this section was excerpted and adapted from: Hsiao, T.C., Heng, L.K., Steduto, P., Rojas-Lara, B., Raes, D., and Fereres, E. 2009. "AquaCrop—The FAO Crop Model to Simulate Yield Response to Water: III. Parameterization and Testing for Maize". Agronomy Journal 101: 488–498.

latter two presenting very different climatic conditions (as well as soil conditions in the case of Florida) compared to Davis. The parameters were further adjusted accordingly and used in the simulations described below for the Davis data.

Working mainly with data sets from six years of maize field experiments at Davis (California, USA), plus another four years of Davis maize canopy data, a set of conservative (nearly constant) parameters of AquaCrop, presumably applicable to widely different conditions and not specific to a given crop cultivar, was evaluated by test simulations, and used to simulate the six years of Davis data. The treatment variable was irrigation - withholding water after planting continuously, only up to tasseling, from tasseling onward, or intermittently, and with full irrigation (FI) as the control variable. From year to year, plant density (7–11.9 plants m−2), planting date (14 May-15 June), cultivar (a total of four), and atmospheric evaporative demand varied. The conservative parameters included: canopy growth and canopy decline coefficient (CDC); crop coefficient for transpiration (Tr) at full canopy; normalized water productivity for biomass (WP); soil water depletion thresholds for the inhibition of leaf growth and of stomatal conductance, and for the acceleration of canopy senescence; reference harvest index (HIo); and coefficients for adjusting harvest index (HI) in relation to inhibition of leaf growth and of stomatal conductance. With all 19 parameters held constant, AquaCrop simulated the final aboveground biomass within 10 percent of the measured value for at least 8 of the 13 treatments (6 years of experiments) and also the grain yield for at least five of the cases. In at least four of the cases, the simulated results were within 5 percent of the measured value for biomass as well as for grain yield. The largest deviation between the simulated and measured values was 22 percent for biomass, and 24 percent for grain yield. Importantly, the simulated pattern of canopy progression and biomass accumulation over time were close to those measured, with Willmott's index of agreement (d) for 11 of the 13 cases being ≥0.98 for canopy cover (CC), and ≥0.97 for biomass. Accelerated senescence of canopy due to water stress, however, proved to be difficult to simulate accurately; of the six cases, the index of agreement for the worst one was 0.957 for canopy and 0.915 for biomass. Possible reasons for the discrepancies between the simulated and measured results include simplifications in the model and inaccuracies in measurements.

3.2 CROPWAT[34]

Author	Food and Agriculture Organization of the United Nations (FAO)
Year	1992
Type	Planning; Monitoring
Application level/scale	Local; Farm
Primary users	Governments; Operators
Availability	Free
www.fao.org/nr/water/infores_databases_cropwat.html	

OVERVIEW

CROPWAT is a computer program for the calculation of crop water requirements and irrigation requirements based on soil, climate, and crop data. In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of water supply schemes for varying crop patterns. CROPWAT can also be used to evaluate farmers' irrigation practices and to estimate crop performance (yield) under both rain-fed and irrigated conditions.

SCOPE

The CROPWAT 8.0 program includes six modules in order to assess the efficiency of the irrigation system design based on crop water requirements. The modules provide assistance in calculating: 1) climatic conditions and evapotranspiration rate (ETo) - based on temperature, sunshine, humidity, and windspeed; 2) effective rainfall; 3) crop and cropping pattern; which are then referenced and feed into the module on 4) crop water requirements and 5) soil data. The results of these five modules then feed into the type of irrigation system and level of supply required for the crops and area under consideration; and finally 6) the irrigation scheduling module assists users in further tailoring the irrigation system.

AIMS AND OBJECTIVES

The overall objective of the CROPWAT 8.0 program is to assist producers in designing, implementing, and monitoring irrigation systems for the type of crops, climate, and water availability for their production. The program can also be used by policy-makers in compiling data on specific crop water requirements and irrigation options to maximize the efficient use of water for optimal yields.

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34 The information included in this section (excluding the example) was either excerpted or adapted from the FAO's CROPWAT website: http://www.fao.org/nr/water/infores_databases_cropwat. html

METHODOLOGY AND REQUIRED DATA AND SKILLS

As a starting point, and only to be used when local data are not available, CROPWAT 8.0 includes standard crop and soil data. When local data are available, these data files can be easily modified or new ones can be created. Likewise, if local climatic data are not available, these can be obtained for over 5 000 stations worldwide from CLIMWAT[35], the associated climatic database. The development of irrigation schedules in CROPWAT 8.0 is based on a daily soil-water balance using various user-defined options for water supply and irrigation management conditions. Scheme water supply is calculated according to the cropping pattern defined by the user, which can include up to 20 crops. No specialized skills are required in order to use CROPWAT, other than a basic understanding of agriculture, crop water requirements, and irrigation systems. CROPWAT has been developed to be easy to use in a developing country context.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

CROPWAT 8.0 could be used to assess water requirements and irrigation systems for bioenergy crops/feedstocks. One limitation is that CROPWAT does not assess water requirements for the processing stage of bioenergy. Additionally, CROPWAT does not include any assessment of water availability in the area of production or the yield response from water application. It only includes the potential yield reduction if the crop does not have water.

EXAMPLE: USING CROPWAT TO ASSESS THE WATER FOOTPRINT OF BIOETHANOL FROM SUGARCANE[36]

Researchers from the University of Twente (Enschede, The Netherlands) used CROPWAT in a study published by UNESCO. The paper assessed the Water Footprint (WF) of bioethanol from sugarcane, maize and sugar beet. Specifically, CROPWAT was applied to calculate water requirements for the three crops in 19 main producing countries.

With regard to the data used in the study, climate-related information was sourced from the CLIMWAT database[37], a climatic database developed by FAO to be used in combination with CROPWAT. Additionally, when information was not available on CLIMWAT, climatic data was inputted from the Global Climate Data Atlas[38]. Weather stations were selected in the main producing areas for maize in the US and for sugar crops in all selected countries. For maize, one weather station in each country was chosen, for the main producing region.

The study showed that the source (type of crop) and origin (in terms of country, climate

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35 http://www.fao.org/nr/water/infores_databases_climwat.html

36 The information included in this section was excerpted and adapted from: Gerbens-Leenes, P.W., Hoekstra, A.Y. 2009. "The water footprint of sweeteners and bio-ethanol from sugar cane, sugar beet and maize". *Value of Water Research Report Series No. 38*. UNESCO IHE, Institute for Water Education.

37 http://www.fao.org/nr/water/infores_databases_climwat.html

38 http://www.climate1.de/index.html

and agricultural system) of ethanol has a strong impact on its water footprint. Different factors might account for such differences. Low yields, for instance, play a major role in the large water footprint for beet sugar in Ukraine and Russia (21.2 tonne/ha and 23.4 tonne/ha respectively). Based on the differences in WF highlighted in the study, the potential for reducing the water footprint can be analysed, including the selection of alternative sources of feedstock or countries of origin, when this footprint is particularly high.

More detailed assessments should be conducted at the local level in order to further inform on this type of analysis.

3.3 Soil and Water Assessment Tool[39] (SWAT)

Author	United States Department of Agriculture – Agricultural Research Service (USDA-ARS); Texas A&M University
Year	1991
Type	Planning; Monitoring
Application level/scale	National; Local
Primary users	Governments; Operators
Availability	Free
www.brc.tamus.edu/swat	

OVERVIEW

The Soil and Water Assessment Tool (SWAT) is a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds, and to assess water quality issues including nonpoint source pollution problems.

SCOPE

SWAT is a continuous time model that operates on a daily time step and is designed to predict the impact of management on water, sediment and agricultural chemical yields. In SWAT a watershed is divided into multiple sub-watersheds, which are then further subdivided into hydrologic response units that consist of homogenous land use, management and soil characteristics. SWAT can provide a variety of analysis based on specific areas of interest (i.e. nutrient loss, leaching and sediment) and can either simulate results or calculate results based on specific inputs. SWAT interfaces with a range of existing tools and databases including GIS and specific modifications of SWAT that have been developed for specific regions and conditions. SWAT has been used in a variety of applications over the past 25 years to address a variety of types of impacts on watersheds including climate change impacts, hydrologic assessments, pollutant assessments and sediment studies.

AIMS AND OBJECTIVES

The principal objective of SWAT is to predict the effect of management decisions on water, sediment, nutrient and pesticide levels with reasonable accuracy on large, ungauged river basins. SWAT integrates multiple environmental processes to support more effective watershed management decision-making processes and policy-making.

METHODOLOGY AND REQUIRED DATA AND SKILLS

Data inputs include: weather patterns, surface runoff, return flow, percolation, evapotranspiration (ET), transmission losses, pond and reservoir storage, crop growth

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[39] The information included in this section (excluding for the example) was either excerpted or adapted from the SWAT web-site: www.brc.tamus.edu/swat

and irrigation, groundwater flow, reach routing, nutrient and pesticide loading and water transfer. Data can be inputted from measured records and/or generated. Crop yields and/or biomass output can be estimated for a wide range of crop rotations, grassland/pasture systems and trees with crop growth. Planting, harvesting, tillage practices, nutrient and pesticide applications can be simulated for each cropping system with specific dates of rotation or duration. Irrigation practices and sources can also be simulated, including subsequent effects on sediment, nitrogen, phosphorous, pesticides, and bacteria.

A user of SWAT would most likely need to be a trained scientist, agronomist, or have technical, specialized knowledge of watershed management data and inputs.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

Use of SWAT is most suited to specialists/scientists in watershed management and is not a tool that could be easily used by private producers unless they have an scientist or expert on staff in this field. There is also insufficient monitoring data in some areas that results in inaccurate simulations produced through the application of SWAT. SWAT is open source, which is one of its strengths as data is continuously added and edited and the tool benefits from ongoing improvement. However, the lack of spatial data is one of the main limitations of SWAT, and the challenge is in integrating spatial data while maintaining ease of use of the model.

SWAT is suitable for bioenergy operations with no adaptation necessary.

EXAMPLE: USE OF SWAT FOR BIOENERGY PRODUCTION IN THE UPPER MISSISSIPPI RIVER BASIN[40]

A team of scientists tested the application of the Soil and Water Assessment Tool (SWAT) in the Upper Mississippi River Basin (UMRB). The overall objective of the exercise was to suggest a framework to develop SWAT input data for the basin.

Additionally, researchers estimated biomass availability for biofuel production from switchgrass, using SWAT's ability to simulate production of bioenergy crops. In particular, the study converted the entire agricultural area under corn and soybean production along the the UMRB to switchgrass. Data used to apply SWAT to the UNMRB was both annual and monthly streamflow, sourced from 11 monitoring gauges along the basin. SWAT simulations concluded that the UMRB has the potential to produce an average of 17.44 tonnes of biomass per hectare, for a total of 0.38 billion tonnes of biomass per year, if all agricultural land along the basin was converted to switchgrass production.

Limited access to information was the main challenge faced in the study, negatively affecting the tool's performance. Partial data on reservoirs and damns along the UMRB diminished SWAT's potential to capture the size and variability of annual streamflow.

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40 The information included in this section was excerpted and adapted from: Srinivasan, R., Zhang, X., Arnold, J. 2010. "SWAT Ungauged: Hydrological Budget and Crop Yield Predictions in the Upper Mississippi River Basin". *Transactions of the ASABE (An International Journal of the American Society of Agricultural and Biological Engineers)*, 53(5): 1533-1546.

While the tool's performance was satisfying for annual streamflow, its performance was slightly less accurate for monthly streamflow simulations.

Although no specific follow-up activity is recommended in the study, its conclusion highlights the value and prospects of applying accurate spatial input data to SWAT analysis.

3.4 Water Evaluation and Planning[41] (WEAP)

Author	Stockholm Environment Institute (SEI)
Year	1988
Type	Planning
Application level/scale	National; Local
Primary users	Governments
Availability	Free
www.weap21.org	

OVERVIEW

The Water Evaluation and Planning (WEAP) software can be used to represent current water conditions in a given area and to explore a wide range of demand and supply options for balancing environment and development concerns. WEAP provides an integrated approach for assessing the availability of water resources to potentially support, among other things, bioenergy development, and highlights key issues to consider for the sustainable management of water resources. The tool provides a framework for examining alternative water development and management options.

SCOPE

WEAP simulates water demand, supply, flows and storage. WEAP can be used to examine the water resource and socio-economic implications of bioenergy crop expansion through scenario simulations of water demand, supply, runoff, evapotranspiration, reservoir operations, and other variables to examine water usage and implications for bioenergy feedstock production.

AIMS AND OBJECTIVES

WEAP provides a system for maintaining water demand and supply information for policy planning. It can also be used to evaluate a full range of water development and management options, taking into account multiple water users.

As described in Section 2 below, WEAP can be applied to bioenergy. WEAP can also be used to model possible effects of climate change on water supply and demand scenarios.

METHODOLOGY AND REQUIRED DATA AND SKILLS

The effect that bioenergy development scenarios will have on water resources management is explored through the simulation of alternative scenarios which are compared to the baseline (current) situation. The simulation results can then be assessed and evaluated using supply reliability and demand coverage as measuring criteria. WEAP software has an average default value of 75 percent supply reliability as the acceptable level for agricultural water demand, and then the percentage coverage for each scenario is estimated. The impact

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[41] The information included in this section was excerpted and adapted from: http://www.weap21.org

that each scenario has on the reliability of the system is measured by keeping the demand coverage static and measuring how the system responds.

The water supply data required includes: hydrological data on reservoirs (locations, capacity and operation rules); flow gauging station (flow requirement and ecological reserve); information on river head flows; groundwater in addition to irrigation infrastructure and efficiency coefficients, and water returns estimates. On the water-demand side, the following is required: identification of water uses and their allocation; identification of existing agricultural activities; selection of a representative crop mix and water consumption; information on projected expansion of agriculture (including for bioenergy feedstock production), and information on projected population and industrial water uses.

A baseline scenario representing the current situation along with alternative scenarios for future impacts of policies can be used to explore the full range of options for bioenergy development. In this case, scenarios are built based on information collected in the country and assumptions regarding demand from potential bioenergy crop development.

Running the WEAP analysis requires a technical expert with knowledge of computer modelling in the field of water resources.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

The model is available in multiple languages and has been used in many countries in a wide range of contexts. Access to the software for developing countries and education institutions is free of charge. A potential limitation is represented by the technical capacity required to collect the data and then to understand and analyse the results. This capacity might be limited in most developing countries.

The data structure and level of detail can be easily customized to a particular system and analysis. Hydrological data is required for the analysis. Information regarding demand and infrastructure is important as well for the appropriate representation of the water system. If not all data is available, data collection and further processing of any existing data sets on hydrology and of land use- and/or socio-economic data would be required in order to ensure the accuracy of the analysis. Once the system is set up, it is relatively easy to create new scenarios for analysis.

WEAP can support the identification and assessment of the effects of bioenergy crop production on the availability and sustainability of water resources, particularly in water deficient or water stressed regions, informing policy-makers in both water management and bioenergy development. The results provide a basis for policy-makers to identify the availability of water to potentially support bioenergy development and establish boundaries based on trends in supply and demand, in order to ensure the sustainability of supply for "traditional" agriculture and household users as well.

EXAMPLE: FAO'S BIOENERGY AND FOOD SECURITY (BEFS) PROJECT: USING WEAP TO INFORM BIOENERGY POLICY-MAKING IN PERU

Water demand for bioenergy production might result in competition with traditional agricultural and household uses/users, potentially threatening food security.

The FAO's Bioenergy and Food Security (BEFS) project used WEAP to demonstrate the use of a water-modelling tool to support effective water resource planning as part of bioenergy policy analysis. The results of the application of WEAP in the BEFS project serve as a foundation to guide policy-makers in water management planning and bioenergy decision- making.

In Peru, the BEFS project used the WEAP software to assess the water management implications of developing around 25 000 hectares of sugar cane for ethanol production under four different scenarios[42]. The four scenarios included: (1) current situation; (2) under projected expansion of sugar-cane areas; (3) under expansion of sorghum (instead of sugar cane), and (4) under expansion of sugar-cane areas with the expansion of other crops. Considering a 75 percent confidence as the minimum acceptable water provision for agriculture, the following results were obtained. The simulation results were assessed and evaluated using supply reliability and demand coverage as measuring criteria. Results from the BEFS-WEAP analysis showed that the current supply of water would only be enough to support an additional 10 000 hectares of sugar cane in the Chira valley. The model took into account the increase in water demand for population growth through 2030, as well as projected reduction of storage volume of the Poechos dam.

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[42] For further details on the BEFS analysis in Peru, see: FAO. 2010. "Bioenergy and Food Security - The BEFS Analysis for Peru: Supporting the Policy Machinery in Peru". *FAO Environment and Natural Resources Working Paper No. 40*. Rome.

4 WOODY BIOMASS AND RESIDUES

BIOENERGY, WOODY BIOMASS AND RESIDUES, AND FOOD SECURITY

Woody biomass and residues from both agriculture and forestry – in the form of fuelwood and charcoal – are the main sources of energy for most developing countries, especially in rural areas and at the household level (for both cooking and heating). Therefore, access to woody biomass and residues is a key factor for food utilization.

Modern bioenergy development may create a new demand for woody biomass and residues, which can be used to produce heat and power or second-generation liquid biofuels, putting pressure on these resources, and potentially competing with traditional household uses of these resources.

On the other hand, modern bioenergy development may reduce the dependence on fuelwood and charcoal, which are often used inefficiently and unsustainably. In addition to the positive repercussions in terms of access to energy discussed below (see chapter 9), a shift from traditional to modern bioenergy could also reduce the pressure on forests and forest resources from the extraction of wood for household energy use (i.e. cooking and heating).

One tool (WISDOM) was selected to assess (both ex-ante and ex-post) some of the impacts of modern bioenergy on woody biomass and residues discussed above, and to inform the development of a bioenergy sector and of operations that do not lead to an unsustainable use of woody biomass resources and residues. As for the other tools, the intended primary user(s) and the type are specified in brackets:

- **Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM)** (Governments; Planning/Monitoring)

4.1 Woodfuel Integrated Supply/Demand Overview Mapping[43] (WISDOM)

Author	**Food and Agriculture Organization of the United Nations (FAO)**
Year	2003
Type	Planning; Monitoring
Application level/scale	Regional; National; Local
Primary users	Governments
Availability	Free
www.fao.org/docrep/008/j5135e/j5135e02.htm	

OVERVIEW

The Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) is a spatially-explicit methodology that maps the supply and demand of biomass for energy uses and quantifies the supply of biomass from both direct and indirect sources. Understanding spatial differences in biomass supply from direct and indirect sources and woodfuel use patterns provides a way to highlight areas showing surpluses and deficits from agricultural, agro-processing and forestry residues and wood energy consumption patterns. This information can inform the decision-making process for the sustainable use of woody biomass and residues for energy production.

SCOPE

WISDOM can be used to assess biomass demand and supply (from both direct and indirect sources) for energy uses. This is done by incorporating, in a GIS-based platform, information on supply of biomass from: native forests and forest plantations; residues from agricultural activities, and agricultural and wood processing industries. Data on both current and projected demand for woodfuel shall be considered as well. The main output is a geo-referenced database that includes both supply and demand and that can be used to generate maps and information on biomass resource availability and woodfuel consumption, and to quantify demand-supply balances and/or imbalances and thus identify "hotspots" (i.e. areas where demand is exceeding supply).

AIMS AND OBJECTIVES

WISDOM identifies the woody and residue biomass that may be readily and sustainably available for energy use. It also identifies the current trends in biomass use for energy, and it indicates areas where interventions are needed to ensure continued supply and/or protection of wood resources (i.e. so called "hotspots"), as well as areas where there are surpluses that could be used, for instance, for bioenergy production.

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43 The information included in this section was excerpted and adapted from: http://www.fao.org/docrep/008/j5135e/j5135e02.htm

METHODOLOGY AND REQUIRED DATA AND SKILLS

The demand module requires socio-economic and demographic data, as well as data on woodfuel consumption from local surveys. For the supply module, detailed land use/land cover inventories and a national forest inventory should be in place. In addition, data would be required on: biomass stocking from non-forest land-use classes (typically from local studies); available infrastructure for wood/biomass transport and processing; agricultural area, productivity and use of primary agricultural residues; agro-industry and forest product industries to determine the generation of secondary residues/by-products, and legal constraints/restrictions for access to forests. Spatial resolution is based on the desired level of detail or the availability of the main parameters i.e. existing demographic data, land use/land cover information.

WISDOM should be applied by a multidisciplinary team of experts in: forest systems; agriculture; energy; GIS analysis; database management; cartography; statistics, and natural resources management. The added value of forming a multidisciplinary team to apply WISDOM is that it can promote inter-sectoral communication and synergies among different actors in both the private and the public sectors.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

One of the main challenges of WISDOM is the lack of the required data, especially data on woodfuel supply, which has been a major issue in wood energy analysis for many years. Often the only piece of data available for the supply module is the national forest inventory. Detailed information on non-forest and other land use classes is not available in most cases. With regard to consumption, often data is available only for part of the country and sometimes is collected using incompatible methodologies. This data gap can be overcome by: (1) using a proxy variable to *"spatialize"* discontinuous values; (2) extrapolating information available at the project level to an entire study region, and (3) filling specific or critical data gaps with new data coming from field studies. The main challenge is to find direct or proxy variables available at the national level that can be used to estimate production/consumption parameters and their spatial distribution.

The WISDOM methodology is flexible and adaptable to different conditions and scales and can provide a basic structure for analysing a variety of scenarios, variables, and end uses. While the methodology is flexible, it is not standardized in such a way that it is easily packaged and applied by users, especially in developing countries with limited capacity.

EXAMPLE: FAO'S BIOENERGY AND FOOD SECURITY (BEFS) PROJECT: USING WISDOM TO INFORM BIOENERGY POLICY-MAKING IN PERU

As in most developing countries, woodfuel and charcoal in Peru are the main sources of energy in rural areas and poor urban dwellings, with about 11 percent of total domestic energy production obtained from these solid biomass sources. Forests are a key source of woody biomass (and other products as well). Agricultural residues, especially along the coast and in the forest, can be another important source of biomass for energy. Mapping

of woodfuel supply and demand in Peru by the BEFS project using the WISDOM methodology showed that, out of a total of 194 provinces, 58 have supply deficits in woodfuel[44]. These deficit areas are concentrated primarily in the coastal and Sierra regions and are primarily caused by demand for woody biomass for cooking and heating where the supply from native forestry is being stressed.

The Sierra highlands show a deficit "hotspot" where the forestry resource is endangered. The main source of woody biomass for cooking and house heating in the highlands originates from the communal native forests, which are especially vulnerable to overexploitation due to their low resilience capacity. In places where forests have been depleted, communities tend to obtain their timber mostly from shrubs rather than trees. In the coastal region the main source of woodfuel and charcoal comes from the dry forests of the North, which are being overexploited. In fact, the WISDOM-Peru analysis confirms deficits in the supply of woodfuels in those provinces that have these types of forests. Indeed, these deficits may be even higher, since there were insufficient data on charcoal and woodfuel use by the industrial and commercial sectors. In the provinces of the selva region the balances show large surpluses of woodfuel, largely from residues of forest extraction activities in natural forests. The exception is the city of Iquitos and its surroundings, where the balance is negative. Taking into account indirect biomass generated from residues from field crops, agro-industry and wood processing industries in the analysis, the biomass balance of some areas improves. This is the case in several provinces in the coastal region, where the agricultural and agro-industrial activities generate important amounts of residues. Areas that showed net deficits in woodfuel supply switch to having net surpluses when these types of residues are considered.

Out of the 70 000 small settlements of Peru, 50 000 of the smallest and most remote, still lack electricity. Reaching these households involves the highest costs in terms of extending the electrical network. There is an ongoing debate in Peru as to whether these populations should be resettled or if, in turn, technological alternatives should be sought to guarantee them energy supply. The WISDOM analysis shows that many of Peru's regions have important volumes of biomass that could potentially be used to provide local energy solutions in rural areas. However, it remains to be determined what proportion of this biomass will actually be feasible for energy generation in each region. This would require extending the WISDOM analysis to carry out a more localized analysis in particular regions in order to define what is feasible and what is not. For example, woody biomass (including those derived from the harvesting of natural forests) and residues from forestry industries in the selva could be a potential source of energy for rural populations, either through direct use (i.e. burning for local electricity generation) or through the production of briquettes and biofuels using thermo-chemical processes. These two products could also be transported over long distances to areas that present woodfuel deficits.

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44 For further details on the BEFS analysis in Peru, see: FAO. 2010. "Bioenergy and Food Security - The BEFS Analysis for Peru: Supporting the Policy Machinery in Peru". FAO Environment and Natural Resources Working Paper No. 40. Rome.

5 GREENHOUSE GAS EMISSIONS

BIOENERGY, GREENHOUSE GAS EMISSIONS, AND FOOD SECURITY

The potential greenhouse gas (GHG) emissions reductions that biofuels may deliver compared to fossil fuels are one of the key drivers of the growing global demand for modern bioenergy. For this reason, the GHG emission balance is a key determinant of the competitiveness of a biofuel supply chain on the international market. The more competitive the biofuel sector is in a given country, the higher will be the potential for income and export revenue generation from the sector, with positive effects respectively on people's purchasing power and access to food, and on the country's macroeconomic and food stability over time.

The GHG emission balance of biofuels is also a good proxy for the efficiency in the use of land, water, energy and inputs such as fertilizers throughout the biofuel supply chain; the higher this efficiency, the lower the potential competition with food production.

Six tools were selected to assess (both ex-ante and ex-post) the greenhouse gas emission reductions (potential or achieved) delivered by modern bioenergy and to inform the development of a bioenergy sector and of operations that maximize the GHG emission reduction potential of modern bioenergy compared to fossil fuels. These tools are listed below. For each of them, the intended primary user(s) – i.e. governments and/or operators – and the type – i.e. planning and/or monitoring – are specified in brackets:

- **EX-ACT (Ex Ante Carbon-Balance Tool)** (Operators; Planning)
- **GHGenius** (Governments/Operators; Planning/Monitoring)
- **Global Emissions Model for Integrated Systems (GEMIS)** (Governments; Planning/Monitoring)
- **Resources and Energy Analysis Programme (REAP)** (Governments/Operators; Planning/Monitoring)
- **SimaPro** (Governments/Operators; Planning/Monitoring)
- **The Greenhouse Gases, Regulated Emissions, and Energy Use in Transport Model (GREET)** (Governments/Operators; Planning/Monitoring)

5.1 EX-ACT[45] (Ex Ante Carbon-Balance Tool)

Author	Food and Agriculture Organization of the United Nations (FAO)
Year	2010
Type	Planning
Application level/scale	Local; Farm
Primary users	Operators
Availability	Free
www.fao.org/tc/exact/en/	

OVERVIEW

EX-ACT (EX Ante Carbon-balance Tool) is a land-based accounting system, measuring C stocks and stock changes per unit of land, expressed in tCO_2e/ha and year. EX-ACT has been developed by the Food and Agriculture Organization of the United Nations (FAO) to assist project designers in implementing management strategies and practices that deliver greater economic and climate change mitigation benefits.

SCOPE

The EX-ACT tool includes estimations of greenhouse gas emissions and sequestration, based on a series of modules that address the following areas: land use and land-use change, afforestation and reforestation, cropland, perennial crops, rice, grassland, livestock, inputs (e.g. fertilizer) and investment (fuel and electricity use). It estimates the C balance, expressed in tonnes (t) CO_2 equivalents (1 t CO_2-eq is 1 Mg CO_2-eq), between two scenarios: expected with and without project activities.

AIMS AND OBJECTIVES

EX-ACT is aimed at providing *ex-ante* assessments of the impact of agriculture and forestry development projects on GHG emissions and carbon sequestration.

METHODOLOGY AND REQUIRED DATA AND SKILLS

Ex-ACT has been developed based on the IPCC's Guidelines for National Greenhouse Gas Inventories (IPCC, 2006[46]) and other existing methodologies and default values for mitigation options. Default values are primarily from IPCC (2006[47]). Other data inputs such as embodied GHG emissions for farm operations, transportation inputs, and

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45 The information included in this section (excluding the example) was either excerpted or adapted from: EX-ACT EX-Ante Appraisal Carbon Balance Tool, EASYPol - Online Resource Materials for Policymaking www.fao.org/docs/up/easypol/768/ex-act_flyer-nov09.pdf

46 IPCC. 2006. Guidelines for National Greenhouse Gas Inventories, [Eggelston, S.; Buendia, L.; Miwa, K.; Ngara, T.; Tanabe, K.(eds.)]. Kamiyamaguchi, Japan: Institute for Global Environmental Strategies (IGES).

47 *Ditto*.

irrigation systems are from Lal (2004[48]). Ex-ACT consists of a set of linked Microsoft Excel sheets in which the project designer can insert basic data on land use and management practices foreseen under the project's activities. Ex-ACT adopts a modular approach, with each module describing a specific land use and following a three-step logical framework:

- general description of the project (geographic area; climate and soil characteristics; and duration of the project);
- identification of changes in land use and technologies foreseen by project components using specific modules (deforestation, afforestation and reforestation; annual/perennial crops; rice cultivation; grasslands; livestock; inputs; and energy use and type); and
- computation of carbon balance with and without the project using IPCC default values and, when available, *ad-hoc* coefficients.

The main output of the tool consists of the carbon balance resulting from project activities.

EX-ACT requires an understanding of land use and greenhouse gas emissions in order to use it, and to interpret the data requires a more sophisticated understanding in order to apply the results to project development.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

EX-ACT can be used in the context of bioenergy operations to determine the GHGs from change in land use and crop management, but does not represent a full life cycle analysis since it does not consider transportation or end use. Other limitations are outlined in a recent study analysing EX-ACT's application in a variety of case studies[49]. Limitations include difficulty to define the limits of the assessment in terms of specific interventions impacts and the impact of interventions over multiple years; difficult to apply at smallholder level; risk of double counting with linked processes; Excel basis of the tool limits its application, and results are not shown in economic terms. For a complete description and discussion of the strengths and weaknesses of EX-ACT, refer to the Jonsson et al. (2011) study.

EXAMPLE: EX-ACT SOFTWARE FOR CARBON-BALANCE ANALYSIS OF INVESTMENT PROJECTS. AN APPLICATION TO THE ACCELERATED FOOD SECURITY PROJECT IN TANZANIA[50]

A team of professionals from FAO applied the EX-Ante Carbon balance Tool (EX-ACT) in a joint FAO/World Bank (WB) project in Tanzania. The application of EX-ACT in

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48 Lal, R. 2004. "Carbon sequestration in soils of central Asia". Land Degradation & Development, 15: 563-572.

49 Jonsson, M., Tinlot, M., Touchemoulin, O., Bockel, L., Bernoux, M. Forthcoming. *The Limits and Opportunities of the EX-Ante Carbon Balance Tool*. Rome: Food and Agriculture Organization of the U.N. (FAO).

50 The information included in this section was excerpted and adapted from: Bockel, L., Branca, G., Tinlot. M. 2010. "Ex-Act Software for Carbon-Balance Analysis of Investment Projects. An application to the Accelerated Food Security project in Tanzania". *EASYPol Module 111*.

the context of this project and the associated results were discussed in a paper (Bockel et al., 2010), as part of a set of documents aimed at training project developers on how to use this tool. Specifically, the paper offers a case study of carbon-balance appraisal for an investment project by providing an analysis of the impacts of project activities on GHG emissions and carbon sequestration, calculated with EX-ACT.

Data on the following agricultural inputs were considered for the EX-ACT calculations: urea; synthetic Nitrogen (N) fertilizers (maize); synthetic Nitrogen (N) fertilizers (non upland rice); and Phosphorous (P) synthetic fertilizers. As described in section 1.4, EX-ACT focuses on expected GHG emissions derived from production, transformation, and application of fertilizers, based on the default values provided by the IPCC (see footnote 3).

As discussed by Bockel et al. (2010), according to the EX-ACT calculations, the project was found to create a total emission of about 7 million tCO2e , along with a total sink of 12.6 million tCO2e, with a net sink carbon balance of 5.6 million tCO2e in a 20 year time span. The main sources of GHG emissions identified within the project were: rice crops, agricultural inputs and irrigation infrastructure. The promotion of sustainable agricultural practices in the cultivation of maize was identified as the main source of carbon sink. Given the sensitivity of these results to changes in maize management practices, Bockel at al. (2007) recommended that the project include work on the adoption of long-term sustainable agricultural practices, such as conservative agriculture and rainwater management.

5.2 GHGenius[51]

Author	**Natural Resources Canada**
Year	1999
Type	Planning; Monitoring
Application level/scale	National
Primary users	Governments; Operators
Availability	Free
www.ghgenius.ca	

OVERVIEW

The GHGenius model was developed by Natural Resources Canada in 1999, based on the Lifecycle Emissions Model (LEM)[52]. GHGenius can be used to analyse the emissions associated with the production and use of both traditional and alternative fuels in the transport sector, as well as in a few stationary applications.

SCOPE

GHGenius can be used to estimate life-cycle emissions of both primary greenhouse gases[53] and criteria pollutants[54] from combustion and process sources, through each of the following stages: feedstock production and recovery; fertilizer manufacture; land use changes; leaks and flaring; feedstock transport; fuel production; emissions displaced by co-products; fuel storage and distribution; fuel dispensing at retail level; vehicle operation; carbon in fuel; vehicle assembly and transport; and materials used in the vehicles.

GHGenius can be used to analyse the emissions from conventional and alternative fuelled internal combustion engines of: light-duty vehicles; heavy-duty trucks (from classes three to eight); urban buses; light-duty battery powered electric vehicles; and fuel cell vehicles. Overall, approximately 200 vehicle, fuel and feedstock combinations (pathways) can be dealt with by the model.

AIMS AND OBJECTIVES

GHGenius can estimate emissions for past, present and future years (up to 2050) and can perform the life cycle analysis for specific regions and provinces of Canada, and for India, Mexico and the United States. In addition, it can be adapted and applied in other countries as well.

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51 The information included in this section (excluding the example) was either excerpted or adapted from the GhGenius web-site: www.ghgenius.ca

52 For a description of LEM, see: Delucchi, M.A. 2002. *Overview of the Lifecycle Emissions Model (LEM)*. University of California Davis, Institute of Transportation Studies.

53 These include: carbon dioxide (CO_2); nitrous oxide (N_2O); methane (CH_4); and ozone (O_3).

54 These include: carbon monoxide (CO); nitrogen oxides (NO_x); non-methane organic compounds (NMOCs); sulphur dioxide (SO_2); and total particulate matter.

METHODOLOGY AND REQUIRED DATA AND SKILLS

Data and projections for the United States were sourced mainly from the Department of Energy's Energy Information Administration and, secondarily, from the United States Census reports. For Canada, the main data sources included reports by Statistics Canada, Natural Resources Canada, Environment Canada and the National Energy Board.

The non-energy related process emissions in the model are based mainly on the US Environmental Protection Agency (EPA)'s AP-42 emission factors[55]. The emissions from the use of conventional fuels in vehicles were derived from the Environment Canada's model Mobile 6.2C[56]. For alternative fuels, such as biofuels, emissions are based on analysis performed by the US EPA, or derived from available literature.

GHGenius is populated with data for each of the processes included in the model. However, an input sheet is provided in order to allow the users to customize the LCA to their specific needs.

Emissions from co-products are calculated based on system expansion (if data is available), or alternatively based on the displacement method[57]. Greenhouse gas default values are based on IPCC weighting factors.

In terms of required skills, GHGenius requires the user to be familiar with quantitative analysis and GHG related data sources.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

The main limitation of GHGenius is that it can be applied as such only to Canada, India, Mexico, or the United States, as currently data is available only for these countries.

GHGenius can be used to conduct life cycle analyses of bioenergy production and use in the aforementioned countries. In addition, it can be adapted and used for bioenergy-related analyses in other countries as well (see, for instance, the example below).

EXAMPLE: USING A COUNTRY-SPECIFIC GHG MODEL BASED ON GHGENIUS TO COMPARE THE GHG EMISSIONS OF DIESEL AND BIODIESEL PRODUCTION IN THAILAND[58]

Researchers from Kasetsart University in Bangkok applied GHGenius to the study of GHG emissions of transportation fuels in Thailand. Building on GHGenius, a country-specific GHG model was developed, based on Thailand's Life Cycle Inventory data. The specific aim of the assessment was to compare GHG emissions of conventional diesel and palm oil-based biodiesel.

The extraction of crude oil (for diesel) and the production of palm oil (for biodiesel),

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55 http://www.epa.gov/ttnchie1/ap42/
56 http://www.tc.gc.ca/eng/programs/environment-urban-menu-eng-1799.htm
57 Additional information on the GHGenius Web site: http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/2007_events/tfGHG_Wash2007/2007_GHGenius_GBEP.pdf
58 The information included in this section was adapted from: Saibuatrong, W., Thumrongrut, M. 2009. *Life Cycle Greenhouse Gas Emission Model for Transportation Fuel: A Case study of Diesel and Biodiesel Production in Thailand,* International Conference on Green and Sustainable Innovation.

as well as transportation and refining/processing of both diesel and biodiesel, were considered. Both primary (i.e. on-site interviews) and secondary data sources (i.e. government publications, research reports, and journal articles) were used. As already mentioned, GHGenius was partially adjusted and modified based on country-specific data for Thailand, particularly with regard to the energy used in oil refining, and the distance in feedstock transportation. Gathering detailed and reliable information, both from primary and secondary sources, and modeling the tool accordingly, however, was one of the main challenges faced by the researchers who conducted the assessment.

The main result of the assessment was that GHG emissions could be decreased by 64.71 kg $CO_{2\,eq.}$/GJ fuel through a shift from conventional diesel to palm oil-based biodiesel. Similar assessments could be conducted for other fuels, such as bioethanol, or electricity.

This type of assessments could be conducted in other countries as well, in order to inform the development of national policies and strategies for the development of the biofuel sector.

5.3 Global Emissions Model for Integrated Systems[59] (GEMIS)

Author	Öko Institute
Year	1987
Type	Planning; Monitoring
Application level/scale	National
Primary users	Governments
Availability	Free
www.oeko.de/service/gemis/en/	

OVERVIEW

The Global Emissions Model for Integrated Systems (GEMIS) is a life-cycle analysis programme and database for energy, material, and transport systems. The model is accompanied by a dedicated GEMIS software, which was developed by the Öko Institute and is widely used internationally.

SCOPE

The GEMIS database offers information on:

- fossil fuels, renewables, nuclear, biomass, and hydrogen (including fuel composition, and upstream data);
- processes for electricity and heat generation (including various power plants, co-generators, fuel cells, etc.);
- materials: raw and base materials, and especially those for construction, and auxiliaries (including upstream processes);
- means of transportation (fuelled by diesel, gasoline, electricity and biofuels): airplanes, cars, buses, ships, trains, trucks.

GEMIS covers the entire life cycle in its calculation of impacts - i.e. fuel delivery, materials used for construction, waste treatment, and transport/auxiliaries.

For each process, the GEMIS database covers:

- efficiency, power, capacity factor, lifetime/length;
- direct air pollutants (SO_2, NO_x, halogens, particulates, CO, NMVOC [non-methane volatile organic compounds]);
- greenhouse-gas emissions (CO_2, CH_4, N_2O, SF_6,);
- solid wastes (ashes, overburden, FGD [flue gas desulfurization] residuals, process wastes);
- liquid pollutants (AOX [absorbable organically bound halogens], BOD_5

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59 The information included in this section (excluding the example) was either excerpted or adapted from the Öko Institute's GEMIS web-site: http://www.oeko.de/service/gemis/en/

- ■ [biochemical oxygen demand], COD [chemical oxygen demand], N, P, inorganic salts), and
- ■ land use.

AIMS AND OBJECTIVES

The Global Emissions Model for Integrated Systems has been developed to quantify emissions, including GHG emissions, from various types of production systems.

METHODOLOGY AND REQUIRED DATA AND SKILLS

For each bioenergy pathway considered, the system boundaries need to be established in order to identify which processes and activities must be included in the analysis. Data requirements vary depending on the system boundaries. For a full life-cycle assessment, data is required from the agricultural production all the way to the end use. In particular, data is required on the type and quantity of agricultural inputs used: seeds, fertilizers (both synthetic and organic), pesticides, machinery, diesel consumption in farm operations and transport of goods to the farm. For the processing stages of bioenergy, data is required on: type and amount of feedstock used; water use; fuel and energy use (steam, heat, and electricity); conversion efficiencies, and use of co-generation, etc.

The set of skills required to assess greenhouse gas impacts of bioenergy through GEMIS includes expertise in agriculture, energy and engineering.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

GEMIS relies largely on default values for calculating emissions. This can be useful when developing projections, but the emissions may vary widely in practice. For this reason, whenever possible data from direct measurements should be used. The GEMIS tool is free to use/access and is regularly updated, making it a very accessible/reliable tool.

GEMIS can be used to measure the greenhouse gas emissions associated with different bioenergy pathways. This information can then be used to compare such pathways and ensure that bioenergy development meets the desired greenhouse gas emission reduction objectives. GEMIS can also provide information on some of the potential trade-offs associated with certain bioenergy development pathways.

EXAMPLE: FAO'S BIOENERGY AND FOOD SECURITY (BEFS) PROJECT: USING GEMIS TO INFORM BIOENERGY POLICY-MAKING IN THAILAND

One reason for the growing interest in bioenergy development is as a means to reduce greenhouse gas emissions compared to fossil fuels.

Thailand has established a policy measure for supporting biofuel development with the aim of reducing petroleum imports, diversifying the energy matrix, and reducing GHG emissions. Most of the ethanol currently produced in Thailand comes from molasses. However, some operators are pursuing cassava as a feedstock for ethanol. For this reason, FAO's Bioenergy and Food Security (BEFS) project conducted an analysis of the

potential land-use and crop changes associated with the expansion of cassava production for bioenergy[60]. Based on field surveys, the analysis indicated that some land-use changes (e.g. conversion of some degraded lands to cassava production), as well as crop changes (primarily a shift from productive rice fields to cassava production) may occur. The results of this analysis in Thailand indicated that if rice fields were converted to cassava production for bioenergy, between 48 and 88 CO2eq of GHG emissions (with low and high levels of agricultural intensification, respectively) would be generated for each MJ of biofuel obtained from cassava.

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[60] For further information, see: FAO. 2010. "Bioenergy and Food Security - The BEFS analysis for Thailand". *FAO Environment and Natural Resources Working Paper No. 42*. Rome.

5.4 Resources and Energy Analysis Programme[61] (REAP)

Author	Stockholm Environment Institute (SEI)
Year	2010
Type	Planning; Monitoring
Application level/scale	Regional; National; Local
Primary users	Governments
Availability	Fee[62]
www.sei-international.org/reap	

OVERVIEW

REAP is an environmentally extended input-output-based software tool that calculates the environmental pressures associated with consumption activities. It contains baseline data on greenhouse gases, air pollutants, and ecological footprints at the national and local level in the UK. REAP includes a scenario editor that can be used to explore the environmental pressures associated with changes in population, consumption patterns and production technology over time.

SCOPE

The REAP UK model is a two-region input-output model that distinguishes between products produced in the UK and products imported from the 'rest of the world'. Its economic input-output tables describe the flow of goods and services between the UK and 'rest of the world' for 123 individual sectors over a year. The sectors covered range from agricultural and manufacturing industries to transport, recreational, health and financial services.

AIMS AND OBJECTIVES

SEI's mission is to bridge the gap between science and policy. REAP and its associated tools are used to support this mission through the provision of data, policy analysis, and capacity building workshops. The scenario application in REAP has been used to evaluate regional strategies, create footprint reduction roadmaps, and assess sector specific policies on food, transport and housing. The REAP model has been developed in an effort to try and understand the impacts of consumption and production together. The REAP model seeks to bring evidence on the impacts associated with consumption to policy-makers at all levels of government in the UK.

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61 The information included in this section (excluding the example) was either excerpted or adapted from: Alistair, P., Wiedmann, T., Barrett, J., Minx, J., Scott, K., Dawkins, E., Owen, A., Briggs, J., Gray, I. "Introducing the Resources and Energy Analysis Programme (REAP)". *Working Paper*. Stockholm Environment Institute (SEI).

62 SEI is a not-for-profit research institute so any tool licensing or subscription fees are used to cover the costs of tool development and updates.

METHODOLOGY AND REQUIRED DATA AND SKILLS

Environmental data from the supply chain of a product can be assigned to the point of consumption using the economic relationships depicted in the input-output table. REAP uses UK Environmental Accounts together with International Energy Agency information and global databases (GTAP1, EDGAR2), to distinguish between the environmental impact of industrial sectors in the UK and the rest of the world. By modeling data from the combination of industries needed to produce different products, the environmental impact per pound (£) spent of different consumption categories can be calculated. To provide a consistent set of results at the national, regional and local level, REAP also uses nationally published physical data on energy and fuel use with monetary data on household and government expenditure. Using this approach, REAP can account for the full supply chain impacts associated with the food people eat, the clothes they buy, the way they travel, how they heat and light their homes, as well as the number of other products and services they buy. This allows the user to look at the impacts of individual consumption activities in the context of lifestyles as a whole.

There are no specialized skills required to use REAP, although a basic understanding of scenario development, economics and environmental issues such as climate change, will enable the user to more easily interpret the results.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

The REAP UK model only includes data from the UK so it is limited in its use for other countries, however REAP Sweden and REAP Basque region have also been developed. SEI is also currently collecting data on Indian input-output (IO) tables required for REAP at the national scale and has plans for developing an approach at the state level as well. In addition, SEI has now expanded the applicability of the REAP model to other countries as well, including the 27 EU Member States. This Europe wide REAP tool – EUREAPA[63] will be available for free online before the end of the year (2011) and will include footprint data at the national level for the 27 EU Member States plus 18 non-EU countries as well.

In terms of applicability to bioenergy, the REAP and EUREAPA tools do not currently distinguish between crops for food production and crops for bioenergy, only the environmental impacts for different crop groups are available. It may be possible to combine the information on consumption and import flows in these models with specific data on crops for bioenergy, but this is yet to be done and would require further research. With the expected future expansion of REAP to other countries beside the UK, Europe and India, the relevance of this model for bioenergy will significantly increase.

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63 http://www.oneplaneteconomynetwork.org/eureapa.html

EXAMPLE: USING REAP TO ASSESS THE CARBON FOOTPRINT IN ENGLAND AND WALES[64]

Version 2 of the REAP was used by local authority (NUTS4)[65] and Government Office Region (NUTS2) in twelve sites in England and Wales, in 2004. Experimental results were subsequently published by the Stockholm Environment Institute (SEI), in 2008.

The overall objective of the analysis was to look at consumption activities and carbon footprints of residents in twelve different areas of the country. The final goal was to inform Local Area Agreements in England and Wales on carbon footprint patterns, so to identify and model policies and strategies for footprints reduction. Specifically, the example targeted:

- the ecological footprint in global hectares per capita
- the carbon footprint in tonnes of carbon dioxide (CO_2) per capita
- the greenhouse gas footprint in tonnes of carbon dioxide equivalent (CO_{2eq}) per capita

In terms of data employed, this specific experiment includes the impact of products manufactured in other areas of the UK or in other countries, as long as they are consumed within the screened local constituency. Similarly, the experiment excluded the environmental impact of goods and services produced in the screened local area and exported abroad or outside of their initial local constituency. Data was organized based on 63 household consumption categories, with additional 73 categories connected to public infrastructure (capital investment) and government services.

As a main result of the exercise, it was observed that in 2004, 46 percent of local authorities moved more than 50 places in overall ranking as compared with 2001, reflecting changes in population and consumption patterns, as well as changes in the data source and in the methodology used.

A number of possible improvements to REAP were identified through this study, including: (1) the creation of consistent time series; (2) the introduction of small area data; (3) the reduction of the lag time between footprint results and release year; and (4) the improvement of the local data. Some of the latter have now been completed. For example, REAP now includes a consistent time series at the regional level from 1992-2006 and the data is also available at small areas using local level expenditure data.

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64 The information included in this section was adapted from: SEI. 2008. *Footprint Results For Local Authorities – With background methodology and explanation*. Stockholm Environment Institute.
65 Nomenclature of Territorial Units for Statistics.

5.5 SIMAPRO[66]

Author	**Pre Consultants**
Year	2010
Type	Planning; Monitoring
Application level/scale	Regional; National; Local; Farm
Primary users	Governments; Operators
Availability	Fee
www.pre-sustainability.com/content/simapro-lca-software	

OVERVIEW

SimaPro 7 has been developed by Product Ecology Consultants as a tool to collect, analyse and monitor the environmental performance of products and services, following the ISO 14000 series recommendations[67].

SCOPE

SimaPro covers environmental, social, and economic flows associated with the life cycle of various production processes.

SimaPro 7 is available in three different models:

1. *SimaPro Compact,* which is a simplified version based on life cycle analysis (LCA) embedded wizards. The educational versions of the *SimaPro Compact* are named *SimaPro Faculty* or *SimaPro Classroom.*

2. *SimaPro Analyst* is for LCA experts and analysts who require all the functions embedded in the LCA wizards. The educational version of this licence is named *SimaPro PhD.*

3. *SimaPro Developer* is for experts who want to develop dedicated LCA Wizards or who would like to link *SimaPro* to other software.

AIMS AND OBJECTIVES

The primary aim is to provide an easy to use tool to conduct life cycle analysis for a variety of purposes and scopes with the flexibility to adapt, add, and manipulate data depending on availability and priorities.

METHODOLOGY AND REQUIRED DATA AND SKILLS

SimaPro includes default data covering over 4 000 processes for each stage of the LCA. SimaPro provides the flexibility to add and adapt data inputs. SimaPro also has the

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66 The information included in this section (excluding the example) was either excerpted or adapted from the SimaPro web-site: http://www.pre-sustainability.com/content/simapro-lca-software

67 The ISO 14000 family of International Standards on Environmental Management is available here: http://www.iso.org/iso/iso_catalogue/management_and_leadership_standards/environmental_management/the_iso_14000_family.htm

capability to store new project data in a library for future use on other projects or analysis.

The SimaPro database is structured in three main parts:

1. Project data: Here you store all specific data for the project you are currently working on. You can create any number of projects in your database, in order to keep all your data apart and to facilitate the archiving of projects you no longer want to keep.

2. Library data: This contains data to serve as a resource for your projects. The structure of libraries is similar to projects, but the intended use is different.

3. General data: Here the common supporting data for all libraries and projects is stored, such as unit conversion factors and the central list of substance names.

SimaPro requires that the user selects relevant impact categories for inclusion in the LCA. This requires that the user be relatively well-versed in the inputs and impacts necessary for inclusion in a specific production process, in order to address all the issues presented by particular value chains.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

The cost of use/purchase of the software could be a deterrent for smallholders or individuals.

SimaPro can be used to analyse bioenergy production just as it can be used to analyse any production system, however additional data may need to be input, depending on the specific focus (crop, production system, etc.) of the LCA.

EXAMPLE: LIFE CYCLE IMPACT ASSESSMENT (LCIA) OF PAPER MAKING PROCESS IN IRAN BASED ON SIMAPRO7[68]

Researchers from the University of Malaya (Institute of Biological Sciences, Malaysia) applied SimaPro7 to the LCIA of the paper making process in Iran.

This study aimed at assessing, in particular, the impact of the paper making process on forest resources in Iran. The assessment was carried out using a Life Cycle Impact Assessment (LCA) approach, focusing on paper production at Pars Paper Factory, Southwest Iran.

Although the average output capacity of Pars Paper Factory is metric tonne per year, the unit considered for the purpose of this study accounted for a production of one metric tonne of paper per year. The study identified ten impact categories, namely: abiotic depletion; acidification; eutrophication; global warming; ozone layer depletion; human toxicity; fresh water aquatic ecotoxicity; marine aquatic ecotoxicity; terrestrial ecotoxicity and photochemical oxidation. The LCIA used the CML2 Baseline 2000 method[69]

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68 The information included in this section was adapted from: Poopak, S., Agamuthu, P. 2001. "Life cycle impact assessment (LCIA) of paper making process in Iran". *African Journal of Biotechnology* 10(24): 4860-4870.

69 For further information on this method, see: http://www.earthshift.com/software/simapro/impact-assessment-methods#cml2

developed by the University of Leiden.

The study of Pars Paper Factory showed that its use of bagasse and hydroelectricity (both renewable sources) presents the lowest impact in terms of greenhouse gas emissions (under the "global warming" impact category). On the contrary, heavy fuel oil (in this case mazut, also used in the factory) presents the highest impact. Similarly, chlorine (from the bleaching process) contributes to photochemical oxidation and ozone layer depletion.

The study assumed that there were no waste nor air and water emissions, as well as no by-products in the paper production process. The study suggests that the use of bagasse as input has the lowest impact on global warming in Pars Paper Factory's operations.

5.6 The Greenhouse Gases, Regulated Emissions, and Energy Use in Transport Model[70] (GREET)

Author	**Argonne National Laboratory**
Year	1996
Type	Planning; Monitoring
Application level/scale	Local
Primary users	Governments; Operators
Availability	Free
www.transportation.anl.gov/modeling_simulation/GREET/index.html	

OVERVIEW

The Greenhouse Gases, Regulated Emissions, and Energy Use in Transport Model (GREET) enables the analysis of vehicle fuel cycles, commonly called 'well-to-wheels' analysis, for various fuel/vehicle systems. Based on inputs by the users, GREET conducts simulation studies on energy use and emissions associated with the production and distribution of different transportation fuels, commonly called 'well-to-pump' activities; and analyses the energy use and emissions associated with vehicle operation for advanced vehicle technologies, commonly known as 'pump-to-wheels' activities.

SCOPE

For a given vehicle and fuel system, GREET separately calculates the following:

- Consumption of total energy (energy in non-renewable and renewable sources), gas and fossil fuels;
- Emissions of greenhouse gases - primarily carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) – expressed in CO_2 equivalents; and
- Emissions of six pollutants: volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxide (NO_x), particulate matter smaller than 10 microns (PM10), particulate matter smaller than 2.5 microns (PM2.5), and sulfur oxides (SO_x).

GREET includes more than 100 fuel pathways, including petroleum fuels, natural gas, biofuels, hydrogen and electricity produced from various sources. GREET also includes more than 80 vehicle/fuel systems.

AIMS AND OBJECTIVES

The GREET fuel cycle model was developed to calculate fuel cycle energy use and emissions for various fuel cycle paths. The objective is to provide simulations and

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[70] The information included in this section (excluding the example) was either excerpted or adapted from the GREET website: www.transportation.anl.gov/modeling_simulation/GREET/index.html

calculations based on a full life cycle analysis methodology particularly geared towards transportation fuels/vehicles.

METHODOLOGY AND REQUIRED DATA AND SKILLS

The GREET model (version 1.7) consists of 27 Microsoft Excel sheets each pertaining to specific data, assumptions, and inputs (agricultural, fuel, etc.) for the fuel pathways and systems. GREET provides the option to use available default values or to input specific data and assumptions. No specialized skills are necessary other than a basic understanding of the bioenergy production specifics for data input purposes.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

The model does not include energy use or emissions from transportation of raw and processed materials for each process step. For biofuels the only feedstocks included in the GREET model are corn- or corn stover-based ethanol, soy-based biodiesel, ethanol from farmed trees, herbaceous biomass, and forest residues; therefore not including many pathways prevalent in developing countries such as biodiesel from palm oil. The GREET model uses the displacement method to account for co-products which is not applicable in all regulatory markets for biofuels (allocation method required in certain markets[71]).

EXAMPLE: CALIFORNIA-MODIFIED GREET PATHWAY FOR BRAZILIAN SUGARCANE-BASED ETHANOL[72]

The Californian Air Resources Board used the GREET model to estimate the energy use and greenhouse gas (GHG) emissions associated with the entire pathway of producing ethanol from Brazilian sugarcane as part of the Low Carbon Fuel Standard regulatory process.

The specific objective of the application was to study ethanol that is normally transported via ocean tanker to a California port, distributed, and finally used in a light-duty vehicle.

In terms of data required for GREET's application in California, the original Argonne model was modified to include California specific values and factors, resulting in the so-called CA-GREET model. Modified assumptions were made in relation to feedstock supplies, transport distances, and vehicle emissions. The Air Resources Board analysed two additional scenarios for ethanol produced in Brazil, so that it could take into account enhanced harvesting practices, e.g. mechanical harvesting of cane, and power generation

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[71] For information on methods to account for co-products and the GREET model, see: California Air Resources Board, Expert Group Investigating Indirect Effects of Transportation Fuels. 2010. *White Paper: Issues Related to Accounting for Co-Product Credits in the California Low Carbon Fuel Standard*.

[72] The information included in this section was excerpted and adapted from: California Air Resources Board. 2009. Detailed California-Modified GREET Pathway for Brazilian Sugar Cane Ethanol; California Air Resources Board. 2009. *Detailed California-Modified GREET Pathways for Brazilian Sugarcane Ethanol: Average Brazilian Ethanol, With Mechanized Harvesting and Electricity Co-product Credit, With Electricity Co-product Credit*.

from bagasse for the processing plant and/or for export.

The application of the California-Modified GREET to Brazilian sugarcane-based ethanol provided useful information for future development and refinement of the model. Some values, for instance, might need further refining in order to maximize the performance of the model, especially with regard to the following variables: land-use change effect of biofuel production; and allocation of co-product credits. New pathways might be added to GREET (such as Brazilian sugarcane, Californian sugarcane, CNG/LNG from biogas, biodiesel from yellow grease). Finally, the interface could be made more user-friendly, and further room could be provided for separating and breaking down results in each stage.

6 CROSS-CUTTING

INTRODUCTION

In addition to the tools described in the previous sections, which deal with specific environmental issues, an important cross-cutting tool (i.e. "Land Suitability Assessment") was selected. This tool deals with a broad range of environmental issues, including: biodiversity/agrobiodiversity, soil quality and water availability. As for the other tools, the intended primary user(s) and the type are specified in brackets:

■ **Land Suitability Assessment (Governments; Planning/Monitoring)**

6.1 Land Suitability Assessment[73]

Author	Food and Agriculture Organization of the United Nations (FAO)
Year	1978
Type	Planning; Monitoring
Application level/scale	National
Primary users	Governments
Availability	Free
http://freegeographytools.com/2007/fao-world-climate-data	

OVERVIEW

When considering bioenergy developments, it is essential to compare bioenergy with other current and planned land uses. Land suitability assessments are used to evaluate the suitability of a specific location for producing a particular crop under a defined agricultural management system based on agroclimatic, soil, and landform conditions. This suitability is expressed as a percentage of the maximum attainable yield for each crop considered.

The starting point for the analysis is the definition of land utilization types (LUTs), which consist of the combination of crop types, production systems, and input levels. The specific climatic and soil data relating to each land utilization type (LUT)[74] is compared with the climate, soil and terrain conditions within the country. The land suitability for different bioenergy crops is then classified based on a suitability index which categorizes, in percentage terms, the production capability of a specific location in terms of the maximum attainable yield for the specific LUT considered. The suitability assessment considers all land as potential area for expanding each crop, although obviously not all land is available for agricultural expansion and/or bioenergy development.

Depending on the specific concerns and priorities of the stakeholders conducting the land suitability assessment, a number of filters can be introduced in order to exclude certain areas, such as protected areas or areas under food production.

SCOPE

The land suitability assessment is used in the FAO's Bioenergy and Food Security (BEFS) project to identify the land areas that are suitable for growing bioenergy crops, the amount of these crops that could be produced on such areas and whether these areas are actually available for use and therefore for bioenergy crop production. Areas that are suitable for bioenergy crop production are identified and areas that pose environmental, food production or other potential land use conflicts are also highlighted. The results can be

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[73] The information included in this section (excluding the example) was either excerpted or adapted from: http://freegeographytools.com/2007/fao-world-climate-data

[74] A land utilization type (LUT) is defined as the combination of crop, production, system, and level of input.

complemented with socio-economic data (and related analysis), such as on population distribution, poverty, and food insecurity. This allows policy-makers to implement measures aimed at meeting complementary policy objectives such as improvement of the agricultural sector, rural development, and poverty reduction.

AIMS AND OBJECTIVES

The land suitability assessment can be used to identify land suitable for bioenergy crop production and to determine how existing land can be managed in a sustainable way to allow for both food and bioenergy crop production through potential yield increases and land prioritization based on suitability.

The land suitability assessment assists policy-makers in analysing a combination of agricultural production systems and input levels to inform production strategies such as bioenergy expansion into new areas, the intensification of current lands under agricultural production, or a combination of both.

METHODOLOGY AND REQUIRED DATA AND SKILLS

Georeferenced information is required as an input to characterize land use by location. Georeferenced data on climatic conditions (i.e. temperature and rainfall), soil and landform properties (i.e. soil type, acidity/alkalinity levels, nutrients, texture and slope), and protected areas are required; land cover- and land use-related information is required as well. The following factors should be included in the land utilization type definitions: production system in terms of crop, production technique, and expected type and range of inputs; limits to mechanization on sloping lands; soil requirements for irrigation, and quantification of both human and financial capital associated with various production scenarios.

To conduct a full land suitability assessment, a broad range of experts need to be involved, including: agrometeorologists; agronomists; soil scientists, forestry and environmental experts, and experts in agricultural statistics. To better address policy objectives, agricultural policy and extension officers can contribute to the interpretation of the data, by bringing a different perspective into the analysis.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

The use of georeferenced information is one of the the main advantages of this type of analysis. However, both the availability and quality of such information could be limiting factors. In most cases, the necessary data is not developed and/or maintained by a single entity or institution but rather compiled from different sources, leading to data compatibility problems. Data quality also determines the scale at which the analysis can be carried out. For example, coarse GIS data (in terms of scale and resolution) cannot be used for a detailed local assessment, but only for a national-level assessment. In addition, free GIS software capable of manipulating raster datasets is very scarce, and the cost of most GIS packages can be prohibitive for most developing countries.

As described in the examples below, land suitability assessments can be conducted for key bioenergy crops/feedstocks. Although the methodology is publicly available, training and capacity building activities might be required in order to enable all developing countries to conduct proper land suitability assessments.

EXAMPLE: FAO'S BIOENERGY AND FOOD SECURITY (BEFS) PROJECT: USING LAND SUITABILITY ASSESSMENT TO INFORM BIOENERGY POLICY-MAKING IN TANZANIA, PERU AND THAILAND

FAO's Bioenergy and Food Security (BEFS) project conducted, in coordination with national experts, land suitability assessments for key bioenergy crops in three countries (Peru, Tanzania and Thailand), in order to inform the development of sustainable bioenergy policies. The software that was used by BEFS is designed in Visual Basic and uses a GIS programming language, Arc Macro Language (AML), the native programming language of the ArcInfo Workstation GIS software produced by ESRI[75].

In *Tanzania*[76], where bioenergy is still at an early stage of development, the main objective was to identify available areas suitable for expansion of bioenergy crops while avoiding competition with existing food crops. In addition, the assessment aimed to identify areas where better agricultural management practices could be introduced in order to increase productivity in a sustainable way. Five crops were selected, namely cassava, sugar cane, palm oil, sweet sorghum and sunflower, and were assessed under four agriculture management configurations based on different levels of input and different agricultural management practices. The results indicated the country's potential to increase agricultural productivity both through the sustainable intensification of existing areas under crop production and through land expansion.

In *Peru*[77], water is a major concern, particularly with the expansion of sugar-cane plantations in arid areas. To analyse this issue, the assessment in Peru incorporated irrigated areas for sugar cane to determine suitability. The land suitability assessment also covered palm oil and jatropha under rainfed conditions. The results of the analysis show that given the limited agricultural land that Peru has (less than 5 percent of total land is used for agricultural production), there could be an impact on food prices and food production if bioenergy production is expanded.

In *Thailand*[78], the Land Development Department of the Ministry of Agriculture and Cooperatives carried out the land suitability assessment for cassava, sugar cane, and

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[75] www.esri.com

[76] For further details on the BEFS analysis in Tanzania, see: FAO. 2010. "Bioenergy and Food Security - The BEFS Analysis for Tanzania". *FAO Environment and Natural Resources Working Paper* No. 35. Rome.

[77] For further details on the BEFS analysis in Peru, see: FAO. 2010. "Bioenergy and Food Security - The BEFS Analysis for Peru: Supporting the Policy Machinery in Peru". *FAO Environment and Natural Resources Working Paper* No. 40. Rome.

[78] For further details on the BEFS analysis in Thailand, see: FAO. 2010. "Bioenergy and Food Security - The BEFS Analysis for Thailand". *FAO Environment and Natural Resources Working Paper* No. 42. Rome.

palm oil. Compared with Peru and Tanzania, Thailand already has detailed information and regularly conducts land surveys and validation in the field. This availability of data allowed for more sophisticated analysis under the BEFS project, including on: the cropping pattern; land competition issues; production costs and alternative production and market opportunities for farmers. The analysis was carried out to evaluate agricultural policy targets and crop suitability and to help farmers identify high value crops and yield improvements through sustainable agriculture management.

PART TWO:
SOCIO-ECONOMIC DIMENSIONS

⑦ LOCAL FOOD SECURITY

BIOENERGY AND LOCAL FOOD SECURITY

Modern bioenergy development may have repercussions on local food security, through the multiple environmental and socio-economic effects addressed in the other sections of this report.

In addition, bioenergy demand may contribute to an increase in agricultural production, through land expansion and/or intensification. This may result in an increase or a decrease in the local supply of staple crops for food, depending on the land and the crops/feedstock used for bioenergy, and the extent to which staple crops are displaced or diverted to bioenergy production.

Bioenergy feedstock production may alter the demand for resources and inputs, such as land, water and fertilizers that are used in the production of staple crops for food, potentially competing with the latter.

Modern bioenergy development may create a number of employment and income generating opportunities for local communities, thereby increasing access to food.

Three tools were selected to assess (both *ex-ante* and *ex-post*) some of the impacts of modern bioenergy on local food security discussed above, and to inform the development of a bioenergy sector and of operations that safeguard, and possibly foster, food security. These tools are listed below. For each of them, the intended primary user(s) – i.e. governments and/or operators – and the type – i.e. planning and/or monitoring – are specified in brackets:

■ **Household Welfare Impact Analysis** (Governments; Planning/Monitoring)
■ **Integrated Food Security Phase Classification (IPC)** (Governments/Operators; Planning/Monitoring)
■ **Operator Level Food Security Assessment Tool** (Governments/Operators; Planning/Monitoring)

7.1 Household Welfare Impact Analysis

Author	Angus Deaton
Year	1989
Type	Planning; Monitoring
Application level/scale	National; Local
Primary users	Governments
Availability	Free; Software (STATA) for purchase
ftp://ftp.fao.org/docrep/fao/011/aj990e/aj990e.pdf	

OVERVIEW

A food price increase can have a positive or negative impact on households depending on whether they are net food producers or net food consumers respectively. The Household Welfare Impact Analysis can be used to assess the impacts of changes (and particularly increases) in food prices on household welfare.

SCOPE

The overall household impact is measured by the effect of price change on household net welfare, defined as the difference between producer gains and consumer losses.

A series of household variables can be used to characterize households. The choice of household characteristics to include in the analysis depends on the nature of the policy question at hand. In the case of poverty and vulnerability work, two initial key household characteristics are income quintile group and urban/rural location. However, additional household characteristics could be considered, including: type of land and/or asset ownership, gender of head of household, education level, age, regional location etc.

AIMS AND OBJECTIVES

The overall aim of the household welfare impact analysis is to assess welfare impacts due to price changes (especially food price changes), i.e. which households gain and which households lose from the price change. This type of analysis can help policy-makers identify those segments of the population that are most vulnerable to price changes and can inform the development and implementation of targeted prevention and mitigation measures, including safeguard programmes for the identified vulnerable groups/households.

METHODOLOGY AND REQUIRED DATA AND SKILLS

The starting point for analysing household level vulnerability to increasing food prices is defining the staple food crops in the country based on the per capita calorie consumption ranking.

Households may be both producers and consumers of staple crops. The impact of a change in the price of staple crops on household welfare can be decomposed into the

impact on the household as a producer of these crops and the impact on the household as a consumer of them. In the short run, the net welfare impact will be the difference between the two – i.e. between the producer gains and the consumer losses. More precisely, the short-run welfare impact on households (also referred to as "net benefit ratio") is calculated as[79]:

$$\frac{\Delta w^1}{x_0} = \%P_{p,i} \cdot PR_i - \%P_{c,i} \cdot CR_i$$

where $\Delta w^1 / x_0$ is the first order approximation (i.e. assuming no supply and demand responses in the short run) of the net welfare impact on producer and consumer households deriving from a price change in crop i, relative to initial total income x_0 (in the analysis income is proxied by expenditure);

$P_{p,i}$ is the producer price of crop i;

$\%P_{p,i}$ is the change in producer price for crop i;

PR_i is the producer ratio for crop i and is defined as the ratio between the value of crop production to total income (or total expenditure);

$P_{c,i}$ is the consumer price of crop i;

$\%P_{c,i}$ is the change in consumer price for crop i; and

CR_i is the consumer ratio for crop i and is defined as the ratio between total expenditure on crop i and total income (or total expenditure).

The main data source for the analysis is represented by the Household Income and Expenditure Surveys (HIES), which are available for most countries. Generally, these surveys are available on the web sites of national statistics agencies/offices; in addition, a global catalogue of household surveys has been developed by the International Household Survey Network[80] (IHSN). With regard to the identification of the main staple crops, FAOSTAT[81] provides data on per capita calorie consumption by crop.

This analysis requires expertise in household level data analysis and good knowledge of agricultural markets and price movements. The analysis is performed using the STATA package software[82].

LIMITATIONS AND APPLICABILITY TO BIOENERGY

The household analysis and typology structuring is useful to identify the most important food crops and the most vulnerable segments of the population. Nevertheless, this type of analysis is limited to *short-run* effects whereby more detailed micro-simulation analysis or general equilibrium modelling would be required to determine the full breadth of long-

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79 For more details on this methodology, please refer to: Dawe, D., Maltsoglou, I. 2009. *Analyzing the Impact of Food Price Increases: Assumptions about Marketing Margins can be Crucial.* ESA Working Paper No. 09-02. Rome: Food and Agriculture Organization of the U.N. (FAO).

80 http://www.ihsn.org/home/index.php?

81 http://faostat.fao.org/default.aspx

82 http://www.stata.com/

term and multiplier effects of developing a bioenergy sector within a country. Secondly, a household dataset needs to exist that includes detailed data on both income and expenditure by crop and this is not always the case in developing countries.

The Household Welfare Impact Analysis can be used to assess the impacts on household welfare of food price changes in the context of bioenergy developments. Food prices are affected by other factors as well in addition to such developments, both on the supply and demand sides (e.g. weather conditions, energy and input prices, demographic growth combined with dietary changes, etc.). In order to assess the household welfare impacts arising from bioenergy developments, the share of the food price change that is due to bioenergy should be determined, for instance through the use of computable models.

EXAMPLE: FAO'S BIOENERGY AND FOOD SECURITY (BEFS) PROJECT: HOUSEHOLD WELFARE IMPACT ANALYSIS IN THE CONTEXT OF BIOENERGY DEVELOPMENT IN TANZANIA, PERU AND CAMBODIA

Bioenergy developments represent an additional source of demand for agricultural crops and can thus contribute to increases in the prices of these crops at least in the short run. It is necessary to understand how these price changes can impact, firstly, the country as a whole and, secondly households and their welfare.

In *Tanzania*[83], at the time of the BEFS analysis (i.e. 2008) detailed income and expenditure data by crop was not available[84]. A regional dataset of the Ruvuma and Kilimanjaro collected by REPOA, FAO and the World Bank between 2003 and 2004 was used. This dataset covers rural households from two regions in Tanzania and therefore policy conclusions cannot be drawn for the country as a whole. The analysis showed that the poorest households in Ruvuma benefit from price increases in maize and rice but are negatively hit by price increases in cassava. The poorest households in Kilimanjaro are indifferent to price changes in cassava but stand to lose from price increases in maize and rice. These different results reflect the different positions (as net producers or consumers) of households across the various quintiles in the two regions.

In *Peru*[85], the analysis was conducted at the national level and disaggregated at the regional level. Households were disaggregated into urban and rural. Results showed that an increase in the price of rice, which is the main staple crop in Peru, would have different impacts on different quintiles of the population, as well as on different regions within the country. With regard to the latter, the analysis conducted by the BEFS project showed that an increase in the price of rice would benefit the Northern coastal areas and the Amazon, while all other regions - including the poorest areas in the Central and Southern Sierra

83 For further details on the BEFS analysis in Tanzania, see: FAO. 2010. "Bioenergy and Food Security - The BEFS Analysis for Tanzania". *FAO Environment and Natural Resources Working Paper* No. 35. Rome.

84 The National Panel Survery of Tanzania 2008-2009 now contains household income and expenditure data by crop: http://www.nbs.go.tz/

85 For further details on the BEFS analysis in Peru, see: FAO. 2010. "Bioenergy and Food Security - The BEFS Analysis for Peru: Supporting the Policy Machinery in Peru". *FAO Environment and Natural Resources Working Paper* No. 40. Rome.

- would suffer. Overall, a ten percent increase in the price of rice would result in a 0.1 percent loss of welfare on the poorest segment of the population.

In *Cambodia*[86], and more generally in the Asian context, food security concerns are mostly related to rice, which is the major staple in the region, especially among the poorest households. Since rice itself is not a major bioenergy feedstock, the main link between bioenergy development and food security would be through the potential displacement of rice with bioenergy crops/feedstocks. The Household Welfare Impact Analysis that was conducted by the BEFS project showed that an increase in the price of rice would benefit all households except for the landless poor. Urban female-headed households were found to be particularly vulnerable to increases in the price of rice. Overall, however, land ownership status was found to have a larger influence on the results of the analysis than gender of the household head.

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[86] For further details on the BEFS analysis in Cambodia, see: FAO. 2010. "Bioenergy and Food Security – Household Level Impacts of Increasing Food Prices in Cambodia". *FAO Environment and Natural Resources Working Paper* No. 37. Rome.

7.2 Integrated Food Security Phase Classification[87] (IPC)

Author	**IPC Global Partners: FAO; WFP; FewNet; EC-JRC; Oxfam GB; CARE International; and Save the Children UK-US**
Year	2004
Type	Planning; Monitoring
Application level/scale	Regional; National; Local
Primary users	Governments
Availability	Free
www.ipcinfo.org/index.php	

OVERVIEW

The IPC was originally developed in Somalia under FAO's Food Security Analysis Unit (FSAU). This successful experience led to the development of a standardized IPC approach that is now regularly used in several countries in Africa (Burundi, Central African Republic, Côte d'Ivoire, Democratic Republic of Congo, Ethiopia, Kenya, Somalia, South Sudan, Sudan, Tanzania, and Uganda) and Asia (Nepal and Tajikistan) and is being introduced in many others.

In 2007, FAO hosted an IPC Online Forum in which over 150 experts from 40 agencies reviewed technical and institutional aspects of the IPC. This was followed by an international review meeting where seven agencies and international NGOs (Care International, EC JRC, FAO, FEWS NET, Oxfam GB, Save the Children UK and US, and WFP) agreed on a common approach for further developing the IPC. The resulting proposed multi-agency strategy gained full support from donors at a subsequent special donor partnership meeting.

The IPC is continuously refined and improved based on experiences with its application in different countries. Version 2.0 of the IPC was released at the end of 2011, following an in-depth consultation process with IPC practitioners and based on a number of scientific studies.

SCOPE

The Integrated Food Security Phase Classification (IPC), also known as "IPC scale", is a standardized tool that integrates food security, nutrition, and livelihood information in order to provide timely, reliable and accessible information on the food security situation, especially at the national level.

IPC is used mainly in situations of acute and chronic food insecurity. It can be used both to analyse the current situation and to make future estimates.

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87 The information included in this section was either adapted or excerpted from the IPC Web site: http://www.ipcinfo.org/index.php

AIMS AND OBJECTIVES

IPC aims at providing donors, agencies and governments with a "common currency" for classifying food security, as well as improving food security analysis and related decision-making, by identifying priorities for intervention.

IPC can be used to assess the food security situation at the national and local levels, possibly also to consolidate national analyses at the regional level, and to monitor related changes over time.

METHODOLOGY AND REQUIRED DATA AND SKILLS

The approach of IPC is to draw together all available food security information (or "evidence"), ranging from production figures to livestock prices, and from civil insecurity to malnutrition rates, in order to issue a Phase Classification and/or Risk of Worsening Phase statement. IPC relies on multiple data sources and methods. It uses different methodologies and integrates a wide range of secondary data to assess the food security situation thanks to triangulation of evidence. IPC then provides a "convergence of evidence" approach and a set of tools to get the "big picture", or meta-analysis, of the food security situation.

The main outcomes of the IPC process are final operational maps that present the food security situation for the different areas of a country, accompanied by detailed reports which provide additional information and analyse the underlying causes of food insecurity.

IPC classifies food security according to five levels (called "phases"):

- Generally food secure.
- Moderately/Borderline food insecure.
- Acute food and livelihood crisis.
- Humanitarian emergency.
- Famine/Humanitarian catastrophe.

This severity classification according to international standards guarantees neutrality and allows comparison across space and time.

The IPC process generally includes a number of country experts from a wide range of fields related to food security, such as agricultural economics and nutrition.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

One possible limitation to the accuracy of the IPC analysis is data availability and quality, as IPC does not entail ad hoc collections of data nor does it build on a specific information system, but relies on existing data.

Even though it is not possible to attribute changes in the food security situation directly to modern bioenergy development through IPC, the tool can help identify if food insecurity is related to an issue of availability and what are the underlying causes, and monitor the evolution of the food security situation in areas where modern bioenergy development takes place.

EXAMPLE: IPC APPLICATION IN NEPAL[88]

In 2008, the World Food Programme (WFP) applied the Integrated Food Security Classification System in Nepal, under the framework of the WFP-run Nepal's Food Security Monitoring and Analysis System[89] (FSMAS).

The FSMAS is an integrated system that includes a surveillance component and other analytical activities such as sectoral analysis, baseline surveys, and rapid and impact evaluation assessments. It provides information on 51 of the most vulnerable areas of the country, including conflict-affected and disaster prone districts.

In 2008, WFP decided to pilot the IPC in the context of the FSMAS of Nepal to strengthen the food security (FS) phase classification approach and generate lessons for the global IPC process, and in particular to:

■ improve the food security phase classification scale and reference indicators used in Nepal in line with the IPC standard approach;

■ adopt an analysis template to facilitate and document the analytical process of classifying the food security situation,

■ strengthen the decision-making process to classify areas of food insecurity;

■ improve the methodology used for estimating the number of people food insecure and at risk to food insecurity, and

■ align the cartographic protocols used to produce the maps with the standardized IPC protocol.

The IPC in Nepal includes five phases of food insecurity:

■ Generally food secure.

■ Moderately food insecure.

■ Highly food insecure (starting to affect livelihood assets).

■ Severely food insecure (acute food and livelihood crisis).

■ Humanitarian emergency/Famine.

While the terminology of each phase broadly corresponds to the standard IPC (as of 2008), the main difference in terms of contents is in the third phase, described as "humanitarian emergency" in standard IPC. Specifically, in the Nepal classification, phase three includes "probable occurrence of natural disasters causing losses of food stocks and assets at the limit of society's capacity to cope".

Each of these phases is associated with reference indicators with predetermined thresholds that provide an objective means to distinguish phases and to technically support the phase classification. Twelve indicators were used in the Nepal application of IPC.

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88 The information included in this section was either adapted or excerpted from: WFP. 2008. *Strengthening the Food Security Phase Classification Approach in Nepal – (SENAC project – Nepal component)*. Nepal: World Food Programme.

89 FSMAS was launched by WFP in 2002 to gather and analyse information on food security in the country, and to monitor programme performance especially in the food insecure and conflict-affected areas of the country.

Some of these indicators were adapted directly from the standard IPC, while others were developed ad hoc as country-specific proxies.

The main challenge encountered in the application of IPC in Nepal was the adaptation of the global IPC classification to the actual country situation. Issues such as the IPC phase names, their general description, and the role of coping strategies in determining them, required in-country adaptation.

Overall, the application of IPC in Nepal provided useful information for the further development of the global IPC process. For instance, one of the main recommendations that emerged from the Nepal application was to revise the terminology used to define the food security phases. Based on this and on other applications, the names of these phases were eventually changed. In addition, some of the proxy indicators for food access and availability used by the Nepal IPC classification were recommended for consideration for the standard IPC and future pilots, in light of their demonstrated ability to capture the key factors affecting food security. The assigned thresholds, however, would need to be adapted to the local context considered.

7.3 Operator Level Food Security Assessment Tool[90]

Author	FAO's Bioenergy and Food Security Criteria and Indicators (BEFSCI) Project
Year	2012
Type	Planning; Monitoring
Application level/scale	Farm
Primary users	Governments; Operators
Availability	Free
www.fao.org/bioenergy/foodsecurity/befsci/	

OVERVIEW

Agricultural operations with a bioenergy component[91] can affect food security both positively and negatively. This tool, which was developed by FAO's Bioenergy and Food Security Criteria and Indicators (BEFSCI) project, aims to provide a preliminary indication of both the potential benefits and risks that such operations may pose to food security.

SCOPE

The tool consists of three parts:

1. Change in the supply of food to the domestic market.
2. Resource availability and efficiency of use.
3. Physical displacement, change in access to resources, compensation and income generation.

Each part includes a number of indicators, which address key environmental and socio-economic aspects of agricultural operations that are directly linked to one or more dimensions of food security.

AIMS AND OBJECTIVES

This tool has been developed for use by different parties, including relevant national and local authorities, development banks and operators themselves, interested in assessing how an existing or planned agricultural operation with a bioenergy component may affect food security.

METHODOLOGY AND REQUIRED DATA AND SKILLS

For existing operations, the assessment is based on measured data (from the operation

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90 The information included in this section was either excerpted or adapted from: FAO 2012. *Impacts of Bioenergy on Food Security – Guidance for Assessment and Response at National and Project Levels*. Rome: Food and Agriculture Organization of the UN.

91 In the tool, these are defined as operations that produce agricultural products that can be used as bioenergy feedstocks, or that, in addition, process such feedstocks into biofuels (among other things).

itself), while for planned operations it is based on projected data, which can be extrapolated from the business plan of the operation considered and from any other relevant document available (e.g. Environmental/Social Impact Assessment, Environmental/ Social Management Plan, etc.). When data is not available for the specific operation being assessed, a number of proxies are provided in the tool.

For each indicator included under the three parts that comprise the tool, specific thresholds and a scoring system are provided, based on the following three categories:

- Potential benefit for food security.
- No significant influence on food security.
- Potential risk to food security.

Given the complex nature of food security and the multiple interlinkages and potential trade-offs between the issues addressed by the three categories of this tool, each indicator and the associated scoring should be considered in an integrated way.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

The indicators, thresholds and scores included in this tool aim to provide a preliminary indication of potential risks and benefits for specific aspects of food security arising from agricultural operations with a bioenergy component. A number of assumptions and approximations had to be made in the development of the tool, in order to ensure its practicality and applicability to a wide range of situations. The actual food security impacts of the aforementioned operations will depend, among other things, on a number of environmental, socio-economic, policy and institutional factors that are not captured by this tool.

EXAMPLE

As this tool was finalized at the beginning of 2012, no examples of its application were available at the time this document was published.

8 COMMUNITY DEVELOPMENT

BIOENERGY, COMMUNITY DEVELOPMENT, AND FOOD SECURITY

Modern bioenergy development may provide much needed capital investment to rural areas, thus contributing to the economic and social development of local communities.

In addition, bioenergy companies may implement community development programmes. The effectiveness of these programmes will depend on the extent to which they reflect local socio-economic conditions and customs, as well as the specific needs, capacities and desires of the targeted communities. If not properly designed, these programmes may lead to perverse outcomes, with negative effects on local communities.

One tool (HDI) was selected to assess some of the impacts of modern bioenergy on community development discussed above. As for the other tools, the intended primary user(s) and the type are specified in brackets:

■ **Human Development Index (HDI)** (Governments/Operators; Planning/ Monitoring)

8.1 Human Development Index[92] (HDI)

Author	**United Nations Development Programme (UNDP)**
Year	1993
Type	Planning; Monitoring
Application level/scale	National; Local
Primary users	Governments; Operators
Availability	Free
http://hdr.undp.org/en/statistics/hdi/	

OVERVIEW

The Human Development Index (HDI) is a summary measure of human development. It was developed in 1990 by a team of economists in preparation for the first Human Development Report by the United Nations Development Programme (UNDP) in 1990. Since 1993, HDI has been used and updated by UNDP in the context of this annual report.

SCOPE

The Human Development Index (HDI) is a composite index that measures a country's average achievements in three basic aspects of human development: a long and healthy life (health); access to knowledge (education); and a decent standard of living (income).

AIMS AND OBJECTIVES

The HDI was created to emphasize that people and their capabilities should be the ultimate criteria for assessing the development of a country, not economic growth alone. The HDI offers a powerful alternative to Gross National Income (GNI) for measuring the relative socio-economic progress at national and subnational levels. Comparing HDI and per capita income ranks of countries, regions or ethnic groups within countries highlights the relationship between their material wealth on the one hand and their human development on the other.

METHODOLOGY AND REQUIRED DATA AND SKILLS

HDI combines indicators of life expectancy, educational attainment and income into a composite index. It sets a minimum and a maximum for each dimension, called goalposts, and then shows where each country stands in relation to these goalposts, expressed as a value between 0 and 1.

The education component of the HDI is currently measured by means of years of schooling for adults aged 25 years and expected years of schooling for children of school-going age. The life expectancy at birth component of the HDI is calculated using

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[92] The information included in this section (excluding the example) was either excerpted or adapted from the UNDP's HDI Web site: http://hdr.undp.org/en/statistics/hdi/

a minimum value of 20 years and maximum value of 83.2 years, based on the observed maximum value of the indicators from the countries in the time series, 1980–2010. For the wealth component, the goalpost for minimum income is US$163 (PPP) and the maximum is US$108 211 (PPP), both estimated during the same period, 1980-2011. The decent standard of living component is measured by GNI per capita (PPP US$) instead of GDP per capita (PPP US$) The HDI uses the logarithm of income, to reflect the diminishing importance of income with increasing GNI.

The scores for the three HDI dimension indices are then aggregated into a composite index using geometric mean.

Given the versatility of HDI's applications, although a basic understanding of social economics would be useful for its use, no specific skills are required.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

To reflect country-specific priorities and problems and to be more sensitive to a country's level of development, the HDI appearing in the global HDRs can be tailored so that additional components are included in the calculation.

A country's overall index can conceal the fact that different groups within the country have very different levels of human development. Using disaggregated HDIs at the national and subnational levels can help highlight the significant disparities and gaps: among regions, between the sexes, between urban and rural areas and among ethnic groups.

Another limitation of HDI is that it is difficult to use it to monitor changes in human development in the short term because two of its components, namely life expectancy and mean years of schooling change slowly. To address this limitation, components that are more sensitive to short-term changes - such as the rate of employment, the percent of population with access to health services, or the daily caloric intake as a percentage of recommended intake - could be added to the national HDI.

HDI can be used to assess the linkages between human development and bioenergy operations, and can be adapted to assess the impacts of such operations on the health, education and income of local communities (see example below).

EXAMPLE: USING HDI AND GDI IN SUSTAINABILITY ASSESSMENT OF BIOMASS ENERGY UTILIZATION – JATROPHA CULTIVATION FOR BIODIESEL PRODUCTION, ANDHRA PRADESH, INDIA[93]

The Economic Research Institute for ASEAN[94] and East Asia (ERIA) conducted four pilot projects assessing the sustainability of biofuel production for different feedstocks in East Asia. The study covers four countries, namely: India, Indonesia, the Philippines and Thailand.

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[93] The information included in this section was adapted from: ERIA Working Group. 2009. "Sustainability Assessment of Biomass Energy Utilisation in Selected East Asian Countries". ERIA *Research Project Report* 12 http://www.eria.org/pdf/research/y2009/no12/All_PageRE-VISE101223.pdf

[94] ASEAN is the Association of Southeast Asian Nation: http://www.aseansec.org/

ERIA researchers used the Human Development Index (HDI) and the Gender-related Development Index (GDI) to address the social impact of biofuel production in the country, while Greenhouse Gas Emissions (GHGs) were used to assess environmental impacts and total value added (TVA) to assess economic impact.

As for the data used, for the case study in Hyderabad (India), the study calculated sub-indices of HDI and GDI, based on country-specific data within potential biofuel-related scenarios. Since no data was available to assess political and social status of women in relation to biofuel crop operations, additional social development indicators (SDIs) at micro level were calculated to identify socially deprived groups. For example, Life Expectancy (LE), Adult Literacy Ratio (ALR), and Gross Enrolment Ratio (GER) and Per Capita Income (PCI), together with standard of living, education, health and dwelling units based on higher income depending on plantation of Tree Oils India Limited (TOIL) activities were calculated for the case study. In the example above, the updated HDI for the effected site by TOIL's operation was 0.615, while the average (2009 Report) HDI for India is 0.612 (0.003 higher than standard). Similarly the GDI value for the region was estimated as 0.603, which is approximately 98.2 percent of HDI value.

The study proved the HDI and GDI satisfactory tools to conduct social impact assessments. However, the study also indicates that some modifications in the questionnaire are necessary to account for country specific factors such as feedstock, research and development, and specific biofuel policy.

One of the main challenges in the tool's application was data availability at the local level. The assessed projects presented considerable differences in terms of biofuel feedstock, types of final products and by-products, and the scale and complexity of biofuel production systems. Such diversity required application of tailored equations and procedures for each case. Similarly, sub-indices required data at micro level, which are either difficult to obtain or unavailable. Therefore, one of the limitations of the study is that sometimes data at the national (macro level) were used as a proxy for data lacking at the local (micro level). Additionally, other social development indicators were applied, although not comparable at micro and international level. The main challenge in using additional SDIs is that intertwining indicators at micro and macro level might result in partial conclusions. Particularly, some international SDIs might not be comparable at the national level. In India, for example, the pilot study compares SDIs with data from the National Sampling Survey (NSS). The NSS classifies households based on monthly per capita expenditure (MPCE), using a definition of living standards which might be different from other countries within the same region. Although the study provides with some indications on the sustainability of biofuel production at the micro level for the target countries, a larger scale study would be required as a follow-up activity to the initial assessment.

9 ENERGY SECURITY AND LOCAL ACCESS TO ENERGY

BIOENERGY, ENERGY SECURITY AND LOCAL ACCESS TO ENERGY, AND FOOD SECURITY

The security of energy supply may affect the vulnerability of countries to demand and supply shocks in energy markets. These shocks may affect, the trade balance and overall macroeconomic stability, especially in developing countries, with potential repercussions on food security.

If modern bioenergy development leads to a more diverse energy mix, this may contribute to increase the security of energy supply, with positive effects on the ability of these countries to achieve and maintain the food security of their people over time.

Access to energy, especially to modern energy services, is essential for both social and economic development and thus for food security. Access to energy affects the productivity of the agricultural sector and thus food production/availability. Access to modern energy services for cooking is also important for food preparation/utilization.

Modern bioenergy development may increase access to energy and modern energy services for both productive uses (such as crop and livestock production) and household uses (such as cooking), especially in rural areas, with positive effects on local livelihoods and food security. If modern bioenergy development contributes to reducing the dependence on traditional unsustainable bioenergy sources such as fuelwood and charcoal, this may have positive effects on human health and thus on people's food utilization.

Two tools were selected to assess (both *ex-ante* and *ex-post*) some of the impacts of modern bioenergy on energy security and local access to energy discussed above, and to inform the development of a bioenergy sector that fosters energy security and local access to energy. These tools are listed below. For each of them, the intended primary user(s) – i.e. governments and/or operators – and the type – i.e. planning and/or monitoring – are specified in brackets:

- **Energy Development Index (EDI)** (Governments; Planning/Monitoring)
- **Herfindahl-Hirschman Index** (Governments; Planning/Monitoring)

9.1 ENERGY DEVELOPMENT INDEX[95] (EDI)

Author	International Energy Agency (IEA)
Year	2004
Type	Planning; Monitoring
Application level/scale	Regional; National
Primary users	Governments
Availability	Free
www.iea.org/weo/development_index.asp	

OVERVIEW

The Energy Development Index (EDI) has been developed by the International Energy Agency (IEA) in order to track progress in a country's or region's transition to the use of modern fuels. Since 2004, the EDI is updated and published on an annual basis as part of the IEA's World Energy Outlook.

SCOPE

The EDI has been developed by the IEA in order to better understand the role that energy plays in human development. Thus, the EDI mirrors the UNDP's Human Development Index (HDI) and is composed of four indicators, each of which captures a specific aspect of potential energy poverty.

AIMS AND OBJECTIVES

The EDI was developed by the IEA in order foster a better understanding of the role that energy plays in human development. In addition to being an important tool to raise the international community's awareness of energy poverty issues, the EDI provides a rigorous analytical basis for policy-making and can assist countries in monitoring their progress towards modern energy access.

METHODOLOGY AND REQUIRED DATA AND SKILLS

The EDI consists of four indicators of energy poverty:
- per capita commercial energy consumption: which serves as an indicator of the overall economic development of a country;
- per capita electricity consumption in the residential sector: which serves as an indicator of the reliability of, and consumer's ability to pay for, electricity services;
- share of modern fuels in total residential sector energy use: which serves as an indicator of the level of access to clean cooking facilities; and
- share of population with access to electricity.

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[95] The information included in this section was either excerpted or adapted from the IEA's EDI web-page: http://www.iea.org/weo/development_index.asp

A separate index is created for each indicator, using the actual maximum and minimum values for the developing countries covered. Performance in each indicator is expressed as a value between 0 and 1, calculated using the formula below, and the EDI is then calculated as the arithmetic mean of the four values for each country.

$$\text{Indicator} = \frac{\text{actual value - minimum value}}{\text{maximum value - minimum value}}$$

Given the versatility of EDI's applications, although a basic understanding of energy markets would be beneficial for its use, no specific skills are required.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

The indicators used in the EDI capture the quantity of energy consumed as well as rates of access. However, they do not account for the quality of energy accessed and of delivered energy services, or for the use of multiple fuels at household level.

Another challenge of EDI is data availability, especially in least developed countries. Due to data deficiency, for example, the indicator on per-capita commercial energy consumption fails to take account of biomass resources, including wood, charcoal and biofuels, which are used for productive activities in developing countries. With the introduction of low-emission, high-efficiency stoves, biomass consumption will decline in many countries. Yet the EDI cannot adequately compensate for the fact that this decline will be slower than in those countries where households switch to liquid fuels for cooking, even though the impact on energy poverty could be similar.

Despite the aforementioned limitations, the EDI can provide information about the development of the bioenergy sector in a country, for instance in terms of share of modern fuels (including biofuels) in total residential sector energy use.

EXAMPLE: THE ENERGY DEVELOPMENT INDEX (EDI) IN THE IEA'S WORLD ENERGY OUTLOOK 2010: KEY RESULTS AND TRENDS[96]

The World Energy Outlook (WEO) by the International Energy Agency (IEA) updates the Energy Development Index (EDI) on an annual basis.

As shown in the World Energy Outlook 2010, the EDI results are strongly correlated with those of the Human Development Index (HDI), due to the substantial contribution of energy services to advancing human development.

All Sub-Saharan African countries (except for South Africa) appear in the bottom half of the EDI. The ranking of Asian countries varies greatly. Malaysia, for instance, is in the top ten, while Myanmar and Cambodia are in the bottom ten countries. Pakistan has the highest EDI ranking of countries in South Asia. With regard to Latin American countries,

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96 The information included in this section was excerpted and adapted from: OECD/IEA. World Energy Outlook 2010, Chapter 8 "Energy poverty - How to make modern energy access universal?", Special early excerpt of the World Energy Outlook 2010 for the UN General Assembly on the Millennium Development goals, September 2010.

Venezuela has the highest ranking. Net oil-exporting countries, excluding those in Sub-Saharan Africa, are all in the top third of the EDI ranking.

In terms of changes between 2004 (when the EDI was first created) and 2010, as shown in the World Energy Outlook 2010, many countries have made significant progress in improving access to electricity and clean cooking facilities. With regard to specific countries, in China substantial progress has been made in the delivery of access to modern cooking fuels. In Angola and Congo, the share of the population with electricity access and access to modern cooking fuels has expanded, with most of the achievement coming from urban areas. While there has been progress on both fronts in Bangladesh, Sri Lanka and Vietnam, more progress has been made in household electrification that in the provision of access to modern cooking fuels.

As more and better data become available, the EDI will be augmented in order to enhance the monitoring of progress towards universal modern energy access.

9.2 HERFINDAHL-HIRSCHMAN INDEX[97]

Author	**Orris Herfindahl and Albert Hirschman**
Year	1964
Type	Planning; Monitoring
Application level/scale	Regional; National
Primary users	Governments
Availability	Free

OVERVIEW

The Herfindahl-Hirschman index (HHI) was developed in 1964 as a measure of market concentration. This index can also be used to assess the diversity of the energy supply, which is an important aspect of energy security.

SCOPE

The HHI is measured by the sum of the squares of the shares of energy supplied by different sources, including bioenergy. The HHI ranges from 0 to 1. The closer the HHI to zero, the higher the level of diversification; the closer the HHI to one, the lower the level of diversification.

AIMS AND OBJECTIVES

The comparison of energy diversity with and without bioenergy provides a measure of the impact of bioenergy on diversity. Likewise, an examination of the diversity of bioenergy sources (e.g. in terms of feedstocks and geographical origin) will give an indication of the robustness of these supplies.

METHODOLOGY AND REQUIRED DATA AND SKILLS

The Herfindahl-Hirschman index (HHI) is represented by the following formula:

$$ H \quad = \quad \sum_{i=1}^{N} s_i^2 $$

where s_i is the share of energy supplied by source i and N is the total number of energy sources.

The following data is required in order to assess how bioenergy may affect the diversity of energy supply, and how diverse the supply for bioenergy is:

■ Total primary energy supply from each source, including total domestic bioenergy

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97 The information included in this section (excluding the example) was either excerpted or adapted from the indicator on energy diversity that was internationally agreed under the Global Bioenergy Partnership as part of twenty-four sustainability indicators for bioenergy.

production.

■ Number of significant sources of bioenergy supply and associated amounts of energy (MJ).

The categories can relate to the products being produced such as biofuels (e.g. biodiesel, bioethanol, other liquid biofuels), and bioenergy sources aimed at the heat and/or power generation sectors (e.g. wood chips, pellets, agricultural residues). The sources of supply should take into account the regions where the fuels are produced. Total domestic supply can be generated by aggregating the significant sources of supply.

There are no specialized skills required to apply the HHI given that it is a relatively simple equation. However, basic knowledge of mathematics would be useful.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

The Herfindahl-Hirschman index assesses the diversity of the energy supply, which is only one aspect of energy security.

The categorization of energy supply options influences the outcome of the HHI, introducing some form of subjectivity. To counteract this weakness, detailed analysis may be undertaken to determine whether diversity will really help to provide resilience to physical supply disruptions. An important element of this analysis would be an appraisal of the degree to which physical supply disruptions for one category of energy are translated into price shocks, which can spill over from one market to another. Such analysis would help to determine if an indicator measuring diversity of supply will act as a good proxy for an indicator of security of supply. The HHI can be applied to bioenergy in two ways: 1) to assess how bioenergy may affect the diversity of energy supply (overall), and 2) to assess how diverse the supply for bioenergy is, e.g. in terms of feedstocks and geographical origin.

EXAMPLE: INTERNATIONAL ENERGY AGENCY (IEA): USING THE HERFINDHAL–HIRSCHMAN INDEX TO ASSESS ENERGY SUPPLY CONCENTRATION

The IEA is assessing countries' energy diversity, highlighting price risks stemming from supply (or sellers) market concentration. The assessment of supply concentration is done by means of a Herfindhal–Hirschman Index. A measure of political stability is also included by the IEA, giving extra weight to politically unstable countries based on two of the six 'worldwide governance indicators' of the World Bank[98]. The supply concentration measure for each fuel market is weighted according to the fuel share in primary energy supply to assess a country's vulnerability to these concentration risks. The balance between the parameters for supply concentration and political stability is arbitrary.

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98 http://info.worldbank.org/governance/wgi/index.asp

10 GENDER EQUITY

BIOENERGY, GENDER EQUITY, AND FOOD SECURITY

Modern bioenergy development may affect men and women within households, and male- and female-headed households differently, depending on the specific socio-economic and policy context considered. This reflects men and women's different roles and responsibilities, as well as pre-existing gender-based, socio-economic inequalities, particularly in terms of access to and control of land and productive assets in general, as well as historic discriminatory practices.

Women and female-headed households may be more likely than men and male-headed households to be excluded from modern bioenergy supply chains. This is due to widespread and persistent gender-based inequalities in most developing countries, particularly in terms of access to – and control over – the following resources and assets: land, water and other natural resources; agricultural inputs and equipment; agricultural extension services; credit, particularly formal credit schemes; and markets.

If women and female-headed households are excluded from the benefits of modern bioenergy developments – while potentially being exposed to the risks of the latter – their food security may be affected.

One tool (GDI) was selected to assess some of the impacts of modern bioenergy on gender equity discussed above. As for the other tools, the intended primary user(s) and the type are specified in brackets:

■ **Gender-Related Development Index (GDI)** (Governments/Operators; Planning/Monitoring)

10.1 Gender-Related Development Index[99] (GDI)

Author	United Nations Development Programme (UNDP)
Year	1995
Type	Planning; Monitoring
Application level/scale	Regional; National; Local
Primary users	Governments; Operators
Availability	Free
http://hdr.undp.org/en/statistics/indices/gdi_gem/	

OVERVIEW

The Gender-related Development Index (GDI) measures achievement in the same basic capabilities as the Human Development Index (HDI) does, but takes note of inequality in achievement between women and men. GDI was introduced by the United Nations Development Programme (UNDP) in the *Human Development Report 1995*.

SCOPE

HDI is a composite index that measures a country's average achievements in three basic aspects of human development: a long and healthy life (health); access to knowledge (education); and a decent standard of living (income). The GDI is simply the HDI discounted, or adjusted downwards, for gender inequality. The methodology used to construct the GDI and GEM could be used to assess inequalities not only between men and women, but also between other groups such as rich and poor, young and old, etc.

AIMS AND OBJECTIVES

The UNDP's *Human Development Report* 1995 introduced GDI as a new measure of human development that highlight the status of women. GDI has been used as an advocacy and monitoring tool for gender-related human development analysis and policy discussions.

METHODOLOGY AND REQUIRED DATA AND SKILLS

GDI is a distribution-sensitive measure that accounts for the human development impact of existing gender gaps in the three components of the HDI (i.e. health, education and income). The methodology imposes a penalty for inequality, such that the GDI falls when the achievement levels of both women and men in a country go down or when the disparity between their achievements increases. The greater the gender disparity in basic capabilities, the lower a country's GDI compared with its HDI. Therefore, the GDI is calculated by taking the unweighted average of the three equally distributed indices. Ultimately,

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99 The information included in this section was either excerpted or adapted from the UNDP's webpage on GDI: http://hdr.undp.org/en/statistics/indices/gdi_gem/

the difference between GDI and HDI depends on how much penalty is imposed on the differences between men and women.

Given the versatility of GDI's applications, although a basic understanding of social economics would be useful for its use, no specific skills are required.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

GDI is the HDI adjusted for gender disparities in its basic components. It should not be interpreted as a measure of gender inequality, as has often been the case. To get a measure of gender inequality, one should use the difference or the ratio of two indicators. In addition, the difference between the HDI and the GDI tend to be small because those captured by the three dimensions tend to be small, giving a misleading impression that gender gaps are irrelevant. Due to the aversion to inequality formula used to calculate the GDI, gender disparities relating to employment and quality of education, for example, are not captured.

HDI and GDI can be used to assess the linkages between human development and bioenergy operations, and can be adapted to assess the gender-differentiated impacts of such operations on the health, education and income of local communities (see example below).

EXAMPLE: USING HDI AND GDI IN SUSTAINABILITY ASSESSMENT OF BIOMASS ENERGY UTILIZATION – JATROPHA CULTIVATION FOR BIODIESEL PRODUCTION, ANDHRA PRADESH, INDIA

See section 8.1.

11 CROSS-CUTTING

INCLUDING EMPLOYMENT, WAGES, INCOME AND SMALLHOLDERS INCLUSION

INTRODUCTION

In addition to the tools described in the previous sections, which deal with specific socio-economic issues, a number of relevant cross-cutting tools were selected. These tools deal with a broad range of socio-economic dimensions of modern bioenergy production, including: employment and wages, and income generation and inclusion of smallholders.

Employment and wages are one of the most important means through which people may acquire the financial resources they need in order to purchase food. Employment quality and labour conditions are also important, as they may affect who has access to employment and whether (and which) workers benefit from it.

Modern bioenergy development may create new employment opportunities along the entire supply chain and in particular in bioenergy feedstock production (especially with low mechanization levels). Most of the jobs created in bioenergy feedstock production will be concentrated around the harvest season, and might therefore result in an increase in the flow of migrant workers – who tend to be particularly vulnerable – if sufficient human resources are not available locally.

At the same time, bioenergy production may displace other economic activities and the jobs associated with them, and it might compete, in terms of labour requirements, with other types of agricultural production, including for food.

If bioenergy production leads to an increase in labour demand, wages might be positively affected. However, if good practices are not implemented, bioenergy production may have a negative impact on wages and labour conditions, especially in bioenergy feedstock production. This is due to the fact that feedstock production accounts for a significant share of total bioenergy production costs. In a highly competitive industry and market, this may put a downward pressure on wages and labour conditions. Given their vulnerability, migrant workers might be particularly affected.

Non-wage income (i.e. self-employment) represents another important means through which people obtain the resources they need in order to purchase food.

Modern bioenergy development may create new business and income-generating opportunities, including for smallholder farmers and for small and medium enterprises, along the entire supply chain.

However, there are significant economies of scale often required in the production of bioenergy. This may lead to concentration in bioenergy feedstock production and a push

towards verticaltion integration, thereby excluding smallholders from potentially lucrative global bioenergy markets.

The challenges that smallholder farmers may face in participating in bioenergy certification schemes – which represent a prerequisite to access certain markets – may reinforce this tendency.

Five cross-cutting tools were selected to assess (both *ex-ante* and *ex-post*) some of the impacts of modern bioenergy on the aforementioned issues, and to inform the development of a bioenergy sector and of operations that improve the socio-economic conditions and the food security at national, local and household levels. These tools are listed below. For each of them, the intended primary user(s) – i.e. governments and/or operators – and the type – i.e. planning and/or monitoring – are specified in brackets:

- **BEFS - Computable General Equilibrium Modelling of Economy-Wide Impacts of Bioenergy Development** (Governments; Planning/Monitoring)
- **Biomass Socio-Economic Multiplier (BIOSEM)** (Governments/Operators; Planning)
- **Global Trade Analysis Project (GTAP) Model and Database** (Governments; Planning)
- **Partial Equilibrium (PE) Models: AGLINK-COSIMO and OECD/FAO Agricultural Outlook** (Governments; Planning)
- **Process Engineering for Environmental and Techno-Economic Analysis (PENTA); Bioenergy Techno-economic Analysis for Africa (BIOTA)** (Governments/Operators; Planning/Monitoring)

11.1 BEFS - Computable General Equilibrium (CGE) Modelling of Economy-Wide Impacts of Bioenergy Development

Author	FAO'S Bioenergy and Food Security (BEFS) Project
Year	2010
Type	Planning; Monitoring
Application level/scale	National
Primary users	Governments
Availability	Free
www.fao.org/docrep/013/i1968e/i1968e00.htm	

OVERVIEW

Computable General Equilibrium (CGE) models "calculate an equilibrium state for a system including all relevant economic markets" (Ecofys 2010[100]). CGE models, which provide an effective means of economic analysis, have been often applied to issues of trade policy, income distribution and structural change in developing countries[101].

SCOPE

CGE models cover many areas of a country's real economy. They simulate the functioning of a market economy, including factor and product markets. In addition, these models usually link sectoral production and incomes to a detailed array of household groups.

AIMS AND OBJECTIVES

CGE models have been applied to areas as diverse as fiscal reform, development planning, international trade, environmental regulations and food policy.

They provide a useful perspective on how changes in economic conditions are mediated through prices and markets. In addition, they provide a theoretically consistent framework for conducting welfare and distributional analysis.

METHODOLOGY AND REQUIRED DATA AND SKILLS

CGE models start with a baseline which provides the model's "best estimate" description of the present or future state of the world's markets and agricultural policies (Edwards *et al.* 2010[102]). This baseline is then "shocked" with a change, such as an increase in the

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100 Ecofys. 2010. Indirect effects of biofuel production - Overview prepared for the Global Bioenergy Partenership (GBEP).
101 For a description of the standard CGE model, see: Lofgren, H., Harris, R.L., Robinson, S. 2002. *"A Standard Computable General Equilibrium (CGE) Model in GAMS". Microcomputers in Policy Research 5*. Washington DC, USA: International Food Policy Research Institute (IFPRI).
102 Edwards, R., Mulligan, D., Marelli, L. 2010. *Indirect Land Use Change from increased biofuels demand - Comparison of models and results for marginal biofuels production from different feedstocks*. JRC Scientific and Technical Reports.

demand for modern bioenergy. The results then show changes in a number of important variables, including agricultural and food prices (Edwards *et al.* 2010[103]).

CGE models cover many areas of a country's real economy, and so they require comprehensive economy-wide datasets. The dataset typically underlying a country CGE model is called a "social accounting matrix" (SAM). A SAM is a consistent accounting framework that captures all income and expenditure flows within an economy in a given year. Building a SAM requires data from a wide range of sources (e.g. national accounts, household income and expenditure surveys, trade and tax data, and the balance of payments). Most countries already have a SAM and this can be used to study the effects of biofuels. If a SAM does not exist, there are numerous publications to draw from in order to build one (Thurlow and Wobst 2003[104]; Breisinger, Thomas, and Thurlow 2009[105]). Once a SAM exists, it is necessary to introduce new biofuel sectors based on external production technology data for both feedstock and processing. Information on feedstock production can be found in farm budgets and crop surveys compiled by local ministries of agriculture. Once a SAM containing biofuels has been compiled, it is necessary to use GAMS or GEMPACK mathematical computer programming languages to specify the equations of the model and to calibrate the models' parameters to the information contained in the SAM.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

The results of CGE models are sensitive to the assumptions made and to the choice of input parameters. Another important limitation of CGE models is "the need to limit sectoral and regional disaggregation and the level of institutional detail". For instance, in CGE models the number of agricultural products rarely exceeds ten (Gerdien Prins *et al.* 2010[106]).

Conducting CGE analysis can be complex and requires specialized expertise and experience that may not be available in some developing countries.

The structural nature of CGE models also enables the introduction of new phenomena – such as bioenergy – and to consider differences in the way bioenergy can be produced (e.g. smallholders vs. large estates, or using cassava instead of sugar cane). CGE models are the most appropriate analytical tool when the scale of bioenergy production being examined is large enough to have economy-wide implications.

103 *Ditto*.

104 Thurlow, J. and Wobst, P. 2003. *Poverty-Focused Social Accounting Matrices for Tanzania*. Trade and Macroeconomics Discussion Paper 112. Washington D.C., USA: International Food Policy Research Institute (IFPRI).

105 Breisinger, C., Thomas, M. and Thurlow, J. 2009. *Social Accounting Matrices and Multiplier Analysis: An Introduction with Exercises*. Washington DC, USA: International Food Policy Research Institute (IFPRI).

106 Gerdien Prins, A., Stehfest, E., Overmars, K., Ros, J. 2010. *Indirect effects of biofuels: Are models suitable for determining ILUC factors?* Bilthoven: Netherlands Environmental Assessment Agency (PBL).

EXAMPLE: FAO'S BIOENERGY AND FOOD SECURITY (BEFS) PROJECT: ASSESSING THE ECONOMY-WIDE EFFECTS OF MODERN BIOENERGY DEVELOPMENT IN TANZANIA THROUGH A CGE MODEL

Bioenergy-related investments can have positive or negative impacts on national income, food security and household poverty depending on the choice of feedstock and farming arrangements. This is because, when produced at scale, bioenergy production has economy-wide implications, i.e. for other sectors, labour markets, public sector taxes and non-bioenergy-related exports. Intersectoral linkages arise because bioenergy uses intermediate inputs and so generates demand for other sectors' outputs. Similarly, feedstock production uses agricultural land and labour, which, if not uncultivated or underemployed, must be sourced from other sectors. Bioenergy production might also have fiscal implications, especially if the tax rates imposed on bioenergy are lower than those on fossil fuels. Replacing lost revenues may affect producers and workers outside of the bioenergy sectors. Finally, a large expansion of bioenergy-related exports will influence a country's real exchange rate, with knock-on implications for exporters.

As described in Section 1, Computable general equilibrium models are specifically designed to capture these and other economy-wide interactions and linkages.

The FAO's Bioenergy and Food Security (BEFS) project developed a CGE model to estimate the growth and distributional implications of alternative bioenergy production scenarios in Tanzania (see Thurlow, 2010[107]). The scenarios simulated by the model differed in the feedstock used to produce bioenergy (sugar cane or cassava), and the scale of feedstock production (smallholder outgrower schemes versus large-scale estates). Model simulation results indicated that, while some farmers will undoubtedly move away from producing food crops, there is no national-level conflict between food and fuel production in Tanzania. Rather it is traditional export crops that would be adversely affected by an appreciating exchange rate caused by increasing bioenergy-related exports (or reducing petroleum imports).

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107 Thurlow, J. 2010. "Economy wide effects of bioenergy developments", in: FAO. 2010. "Bioenergy and Food Security - The BEFS Analysis for Tanzania". FAO *Environment and Natural Resources Working Paper* No. 35. Rome.

11.2 Biomass Socio-economic Multiplier[108] (BIOSEM)

Author	FAIR Programme, European Commission
Year	1997
Type	Planning
Application level/scale	Regional; National; Local; Farm
Primary users	Governments; Operators
Availability	Free
www.task29.net/assets/files/reports/Madlener_Myles.pdf	

OVERVIEW

The Biomass Socio-economic Multiplier (BIOSEM) was developed as part of a two-year project within the FAIR Programme under the European Commission's Fifth Framework Programme. Using a traditional Keynesian Income Multiplier approach, BIOSEM makes predictions about the income and employment effects arising from the installation of a bioenergy plant, after having assessed the financial feasibility of the latter.

SCOPE

BIOSEM is a quantitative model that can be used to conduct *ex-ante* assessments of the costs and benefits associated with a proposed bioenergy scheme (covering both feedstock production and processing), and of the resulting socio-economic effects. It can trace both the extent and distribution of income and employment gains, and can assess the merits of differing (energy and agricultural) policy packages, such as grants and subsidies on bioenergy production.

AIMS AND OBJECTIVES

BIOSEM is intended to inform *ex-ante* assessments of the costs and benefits associated with a proposed bioenergy scheme. In particular, it captures the income and employment effects arising from the deployment of bioenergy plants in rural communities.

METHODOLOGY AND REQUIRED DATA AND SKILLS

A range of biomass fuels and conversion processes (e.g. from residues to dedicated energy crops) can be modelled through BIOSEM, as can the recipient markets for heat and electricity. Modelling takes place in two phases: first, to identify the financial feasibility of the plant, and second, to determine the employment and income benefits from the complete bioenergy chain. It evaluates both the backward linkages (i.e. the impact of

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108 The information included in this section (excluding the example) was either excerpted or adapted from: Madlener, R., Myles, H. 2000. *Modelling Socio-Economic Aspects of Bioenergy Systems: A survey prepared for IEA Bioenergy Task 29*. Paper prepared for the IEA Bioenergy Task 29 Workshop in Brighton/UK, 2 July 2000.

increased demand in the supply chain) and the forward linkages (i.e. the re-spending of additional regional income) before combining these figures to provide a complete analysis of the impact of bioenergy production on the local economy.

In order to ensure accuracy, whenever possible operator-specific data should be used; in the event that all the input information cannot be found, the model uses default data from the United Kingdom. This will compromise the validity of the outputs, and therefore every effort should be made to furnish the model with operator-specific data.

Data is only inputted in the first spreadsheet, therefore it is easy for the user to trace the implications of changes in key variables. Similarly, the output is easy to interpret and justify. For this reason, no specific skills are required to use BIOSEM.

11.2.5 LIMITATIONS AND APPLICABILITY TO BIOENERGY

The physical model is no longer available; therefore those wishing to apply this methodology will need to build their own model based on the currently available material on BIOSEM applications over the last ten years.

Notwithstanding this limitation, BIOSEM could be further applied in the future by governments and other interested stakeholders (such as development banks) to assess the costs and benefits of proposed bioenergy schemes and the resulting income and employment effects. BIOSEM could also be used by bioenergy operators as a self-assessment tool.

EXAMPLE: ASSESSING THE ECONOMIC IMPACT OF WESTERN IRELAND'S REGIONAL WOOD ENERGY STRATEGY USING BIOSEM[109]

BIOSEM was used by a group of researchers from ADAS[110] to assess the economic impacts of three market development scenarios included in the *Regional Wood Energy Strategy and Action Plan* of Western Ireland. The economic impacts were estimated based on data included in the Action Plan and consultation with local experts. The study found benchmarks from other BIOSEM studies useful in assessing the potential impacts of the three aforementioned scenarios in Western Ireland. The researchers in this case averaged the BIOSEM results from approximately ten previous studies/applications to come up with an average employment impact of approximately 1.5 to 2.0 FTE (full-time employee) per MW of heat capacity installed.

The data required for input into BIOSEM for this study was collected from three sources: relevant published data, expert onions and consultation with wood energy companies.

According to this study, the main advantage of using BIOSEM is that "it allows for a simple socio-economic assessment to be made for case-specific investigations where data

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109 The information included in this section was excerpted and adapted from: WDC. 2007. *Economic Impact of a Regional Wood Energy Strategy*. Ballaghaderreen, Ireland: Western Development Commission.

110 http://www.adas.co.uk/

is available at the company level" (pg. 14). Although BIOSEM is not as comprehensive as an input-output model, it gives a reasonable estimate of the multiplier effect, as this study found. However, researchers also noted that the data required to run the BIOSEM analysis is rather extensive.

11.3 Global Trade Analysis Project (GTAP) Model and Database[111]

Author	Centre for Global Trade Analysis, Purdue University
Year	2009
Type	Planning
Application level/scale	Regional; National
Primary users	Governments
Availability	Subscription fee
www.gtap.agecon.purdue.edu/models/energy/default.asp	

OVERVIEW

The Global Trade Analysis Project (GTAP) consists of a global network of researchers and policy-makers conducting quantitative analysis of international policy issues, hosted by Purdue University. GTAP has developed a multiregion, multisector, computable general equilibrium model (CGE) – called "standard GTAP Model" (version 6.2 was released in November 2003) – for conducting quantitative analysis of global economic and policy issues. GTAP has also developed a global database (version 7 was released in December 2008).

SCOPE

The GTAP Model gives users a wide range of input options and variables to assess, such as unemployment and tax revenue replacement. The model has been developed in a way that facilitates comparisons with the results of studies based on partial equilibrium assumptions. Following the development of the initial Model, GTAP has developed a series of additional tools, including GDyn and GTAP-E, as variations of the original model, for specific uses and purposes. For example, the GTAP-E model can be used for analysis of climate change issues, while the GDyn Model can be used to determine how changes in policy, technology, population and factor endowments can affect economies over time.

The GTAP Data Base describes bilateral trade patterns, production, consumption and intermediate use of commodities and services. This database has been recently extended to energy including biofuels – see section 1.5) and land use.

AIMS AND OBJECTIVES

GTAP's overall goal is to improve the quality of quantitative analysis of global economic issues within an economy-wide framework. The GTAP Model and database can be used to conduct quantitative analyses of global economic and policy issues.

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111 The information included in this section (excluding the example) was either excerpted or adapted from the GTAP's website: https://www.gtap.agecon.purdue.edu/models/energy/default.asp

METHODOLOGY AND REQUIRED DATA AND SKILLS

The standard GTAP Model is implemented using the economic modelling software GEMPACK[112] (General Equilibrium Modelling Package). Datasets used are supplied by the global GTAP Network - consisting of individuals, agencies and institutions. The use of GTAP requires modelling skills, whose levels vary according to the scope of the analysis and the selection of the GTAP version to be applied.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

The standard GTAP Model presents the same general limitations of CGE models, i.e. sensitivity to the assumptions made and to the choice of input parameters, and "the need to limit sectoral and regional disaggregation and the level of institutional detail" (Gerdien Prins et al., 2010[113]).

The standard GTAP Model and Data Base can be applied to bioenergy. Both of them have been recently extended to improve the treatment of biofuel by-products and accurately represent global land use. The modified model, nicknamed GTAP-BIO further modifies the GTAP-E model to incorporate the potential for biofuels to substitute for petroleum products. Biofuels were also introduced into the GTAP Data Base. The modified database includes data on production, consumption and trade of biofuels including grain-based ethanol, sugar-cane ethanol and biodiesel from oilseeds, as well as data on biofuel by-products.

EXAMPLE: INTRODUCING BIOFUELS INTO THE GTAP-ENERGY MODEL TO ASSESS THE IMPACTS OF BIOFUEL PRODUCTION ON GLOBAL AGRICULTURAL MARKETS[114]

A team of researchers from Purdue University introduced biofuel linkages into the GTAP-Energy model, in order to analyze the impacts of biofuel production on global agricultural markets and land use change. More precisely, these researchers incorporated biofuels (both bioethanol and biodiesel) as energy inputs into the GTAP-Energy database and to the production and consumption structure of the model, building on the work by Burniaux and Truong (2002)[115] and by McDougall and Golub (2007)[116]. They also applied Agro-Ecological Zones (AEZs) information for each of the land using sectors.

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112 http://www.monash.edu.au/policy/gempack.htm
113 Gerdien Prins, A., Stehfest, E., Overmars, K., Ros, J. 2010. *Indirect effects of biofuels: Are models suitable for determining ILUC factors?* Bilthoven: Netherlands Environmental Assessment Agency (PBL).
114 The information included in this section was either excerpted or adapted from: Birur, D.K., Hertel, T.W., Wallace, W.E. 2008. "Impact of Biofuel Production on World Agricultural Markets: A Computable General Equilibrium Analysis". *GTAP Working Paper* 53. West Lafayette, IN (USA): Purdue University, Center for Global Trade Analysis.
115 Burniaux, J., Truong, T. 2002. "GTAP-E: An Energy-Environmental Version of the GTAP Model". *GTAP Technical Paper* 16. West Lafayette, IN (USA): Purdue University, Center for Global Trade Analysis.
116 McDougall, R. and Golub, A. 2007. "GTAP-E Release 6: A Revised Energy- Environmental Version of the GTAP Model". *GTAP Technical Paper* 15. West Lafayette, IN (USA): Purdue University, Center for Global Trade Analysis.

To validate the model, the study projected the biofuel economy forward in time from 2001 to 2006, and then compared the model predictions to historical evidence. The following key drivers of the biofuel market were considered: the hike in crude oil prices; the replacement of MTBE by ethanol as a gasoline additive in the US; and ethanol subsidies and mandates in the EU and the US. Using this historical simulation, key elasticities of energy substitution between biofuels and petroleum products were calibrated for each region.

With these parameter settings in place, in the study conducted by the researchers from Purdue University, the model did a reasonably good job of predicting the share of feedstock in biofuels and related sectors in accordance with the historical evidence between 2001 and 2006 in the three major biofuel producing regions: the US, Brazil and the EU. The results from the historical simulation revealed an increased production of feedstock, partly through the displacement of other agricultural crops. As expected, the trade balance in oil sector improved for all the oil exporting countries, but it deteriorated at the aggregate for the agricultural sectors.

Overall, as shown by this study, the GTAP-E model with biofuels and AEZs offers a useful framework for assessing the impacts of biofuels on global changes in crop production, utilization, commodity prices, factor use, trade and land-use change. However, due to the extremely dynamic nature of the biofuel industry, there are several elements of global biofuel production and trade that are difficult to replicate in the model. When the aforementioned study was conducted, for instance, the model did not account for developing countries' production of feedstocks such as palm oil and jatropha, for which linkages with the biofuel sectors were not established yet. Additional areas for improvement identified in the study include the incorporation of key types of cellulosic ethanol, as well as of CO_2 and other GHG emissions, in order to allow for a comprehensive assessment of the environmental impacts of biofuels.

11.4 Partial Equilibrium (PE) Models: AGLINK-COSIMO and OECD/FAO Agricultural Outlook[117]

Author	Organisation for Economic Cooperation and Development (OECD); Food and Agriculture Organization of the United Nations (FAO)
Year	2004
Type	Planning
Application level/scale	National
Primary users	Governments
Availability	Free, password protected
www.agri-outlook.org/pages/0,2987,en_36774715_36775671_1_1_1_1_1,00.html	

OVERVIEW

Partial Equilibrium (PE) models calculate an equilibrium state for one specific sector i.e. the agricultural sector in this case. They are based on linear relations between prices, demand and production described by linking elasticities. The elasticities are derived from statistical data of past market movements. These models highlight challenges and opportunities that might materialize in some countries/commodity markets as they analyse key relationships and trends that could develop in agricultural markets. Partial equilibrium models facilitate policy and market analysis of agricultural markets by allowing the modeller to observe the impact of various changes in policies and/or market conditions, such as the development of a bioenergy sector.

The OECD-FAO commodity market analysis and agricultural outlook programme provides a consensus on medium-term prospects for the major agricultural commodities. At the centre of the work is the AGLINK-COSIMO model. This recursive-dynamic, partial equilibrium, supply-demand model of world agriculture, developed by the OECD and FAO, covers annual supply, demand and prices for the principal agricultural commodities produced, consumed and traded in each of the countries represented in the model. The model focuses in particular on the potential influence of agricultural and trade policies on agricultural markets in the medium term.

SCOPE

The AGLINK-COSIMO model is used primarily to produce the medium-term OECD-FAO Agricultural Outlook. It is also used in scenario analyses examining the sensitivity of supply, demand and trade to changes in their drivers. The scope of these scenarios encompasses variations of physical, technical and policy variables.

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117 The information included in this section (excluding the example) was either excerpted or adapted from the OECD/FAO Agricultural Outlook web-site: http://www.agri-outlook.org/pages/0,2987,en_36774715_36775671_1_1_1_1_1,00.html

AIMS AND OBJECTIVES

The Agricultural Outlook provides a medium term picture of countries' supply and demand disposition for each country's main commodities. This will assist policy-makers with assessing future demands for agricultural commodities – including food, feed, fibre, and fuel – and their productive capacity to meet all of these demands.

Collaboration with the OECD and FAO on agricultural outlook has significant benefits for national governments. National research efforts can be enhanced by using the AGLINK-COSIMO Model for domestic and global market and policy scenario analyses. The OECD-FAO also helps to establish or strengthen a domestic agricultural outlook programme, including public events, if desired. Ongoing collaboration across participating governments, as well as with OECD and FAO, offers long-term benefits in terms of continually improving market and policy knowledge. To develop such capacity independently would be prohibitively expensive.

METHODOLOGY AND REQUIRED DATA AND SKILLS

The AGLINK-COSIMO model uses projections by other international organizations beside OECD and FAO of key macroeconomic variables, such as income growth, inflation, energy prices (i.e. world oil price) and exchange rates. Technological change is incorporated through improvements in crop yields and livestock performance over time. Competition for land is modeled by cross-price effects. Production costs of agricultural commodities are approximated using the commodity production cost indices, which are calculated based on the key cost components: labour, energy, fertilizer and other tradable and non-tradable inputs. To ensure that up-to-date commodity market data is used in the annual projections, the OECD and FAO secretariats use a diverse array of data sources for the model. Inputs are drawn from national statistical agencies, UN databases, commodity organizations, and consultants. The AGLINK-COSIMO model is currently composed of more than 20 000 equations. It consists of 14 regional modules and 43 individual country models. It endogenously projects 17 international reference prices. The AGLINK-COSIMO model requires the user to have a background in economics and statistics.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

The OECD-FAO Agricultural Outlook provides, through the AGLINK-COSIMO model, an assessment of market prospects for production, consumption, trade, stocks and prices of the main agricultural commodities as well as projections for the use of agricultural commodities in biofuel production. The database is publicly available so there is no cost. Outlooks for countries not individually modelled are not readily available, but can be produced upon request by national governments.

AGLINK-COSIMO can be used to assess the impacts of modern bioenergy development on agricultural markets (see the examples below).

EXAMPLE: FAO'S BEFS PROJECT: USING AGLINK-COSIMO TO INFORM BIOENERGY POLICY-MAKING IN TANZANIA AND THAILAND

Bioenergy could represent a new source of demand for a country's crop production and could potentially offer a source of export earnings to contribute to the balance of payments. At the same time, bioenergy could create challenges for food security and result in increased imports, creating economic inefficiencies and undesired social impacts.

In order to shed light on these issues and assess the impacts of bioenergy development on agricultural markets in Tanzania and Thailand, the FAO's Bioenergy and Food Security (BEFS) project applied, among other things, the AGLINK-COSIMO model.

Tanzania[118]: The OECD-FAO Agricultural Outlook was initially reviewed by Tanzanian officials to ensure that data and consequent projections were consistent with national data sources. Upon review, officials requested that the sugar-cane yield and acreage be adjusted upwards to reflect recent market developments. The revised Outlook was then used as the baseline for the assessment of biofuel production and consumption scenarios under different mandates. At the time the analysis was carried out, the Government of Tanzania was considering a blending mandate of 10 percent for ethanol and 5 percent for biodiesel. Each of these mandates was assessed against a scenario where 314 000 hectares of land were used for biofuel feedstock production, based on current projections from investors. The AGLINK-COSIMO model was used to assess the impact of these mandates and fluctuations in oil prices. By applying these tools, the Government of Tanzania was able to assess various bioenergy production scenarios with respect to variations in oil prices, yield and land area, commodity prices, and other factors over a ten-year period. This analysis assisted Tanzanian policy-makers in defining how to proceed with domestic bioenergy development.

Thailand[119]: A country-tailored module of AGLINK-COSIMO was developed for Thailand, in order to assess how the domestic-agricultural market could evolve over time as a result of the implementation of the Alternative Energy Development Plan (AEDP) biofuel targets. The main conclusions from the application of this country-tailored model provided information for policy-makers on: (1) projections of land requirements to meet biofuel targets; (2) estimations of change in exports and imports in order to meet the domestic biofuel demand, and (3) projections of food demand as a result of income changes. These projections informed the review of existing national policies in order to meet both economic development and renewable energy development targets. The information also provided policy-makers with information on the types of crops that may be most suitable for bioenergy development in Thailand.

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118 For further details on the BEFS analysis in Tanzania, see: FAO. 2010. "Bioenergy and Food Security - The BEFS Analysis for Tanzania". *FAO Environment and Natural Resources Working Paper* No. 35. Rome.

119 For further details on the BEFS analysis in Thailand, see: FAO. 2010. "Bioenergy and Food Security - The BEFS Analysis for Thailand". *FAO Environment and Natural Resources Working Paper* No. 42. Rome.

11.5 Process Engineering for Environmental and Techno-economic Analysis (PENTA); Bioenergy Techno-economic Analysis for Africa (BIOTA)

Author	PENTA: The Chemical, Catalytic and Biotechnological Processes Research Group, National University of Colombia at Manizales BIOTA: FAO's Bioenergy and Food Security (BEFS) Project
Year	2010
Type	Planning; Monitoring
Application level/scale	National
Primary users	Governments; Operators
Availability	Manuals forthcoming; AspenPlus software for purchase

OVERVIEW

The Process Engineering for Environmental and Techno-economic Analysis (PENTA) and Bioenergy Techno-economic Analysis for Africa (BIOTA) have been developed by the National University of Colombia at Manizales. PENTA and BIOTA can be used, among other things, to estimate production costs of different bioenergy options, with an explicit consideration of how bioenergy projects can incorporate smallholders in a financially viable way. Both tools can lend support to governments in their dialogue with the private sector.

SCOPE

PENTA models the industrial bioenergy processes, allowing for the comparison of alternative technologies for producing bioenergy to identify the most technically and economically viable options for commercialization in the country. It uses a commercial process simulator software, Aspen Plus[120]. BIOTA provides an analysis of biofuel production costs based on the selection of parameters for agricultural crop production and biofuel processing, ranging from low to advanced technology/processing options. It can be used to analyse different production scenarios in a simple form to understand the economic and social impacts from a bioenergy project.

The *feedstock production cost* is determined by analysing existing production practices both at the smallholder and commercial level and average prices at the farm gate in the country. The processing costs are determined by assessing both industrial and small-scale conversion options for biomass to bioenergy for the feedstocks considered and the associated technologies and industrial set-up. Scenarios can be developed in order to determine the desired bioenergy production levels, what feedstock is to be used in the process and who is to supply the feedstock, i.e. smallholders, commercial (estate) or a mix

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120 Aspen Plus is a process modelling tool for conceptual design, optimization, and performance monitoring for the chemical, polymer, specialty chemical, metals and minerals, and coal power industries. It is available here: http://www.aspentech.com/products/aspen-plus.aspx

of both (outgrower scheme). The various scenarios can then be compared both in terms of production cost and social benefits (e.g. smallholder inclusion).

AIMS AND OBJECTIVES

The objective of applying the PENTA and BIOTA tools is to determine bioenergy production cost profiles based on country-specific information related both to feedstock production schemes and practices and to the processing technologies and industrial set-up.

Applying these tools can assist in designing policies that pursue social objectives, such as rural development and income generation (e.g. through the inclusion of smallholders in bioenergy production), while still encouraging private investment and attracting foreign capital.

METHODOLOGY AND REQUIRED DATA AND SKILLS

Defining which scenarios to analyse requires information on the existing situation in both the the bioenergy sector and the agro-industry in general. The data requirements depend on the crops/feedstocks considered, including in terms of variety, yield, and cropping pattern. This data is then combined with literature and in-country knowledge on feedstock production costs disaggregated into costs for: seeds; fertilizers; irrigation; labour; harvesting and post-harvest transportation. To evaluate the processing stages, configurations or systems are defined on the basis of the desired production capacity, feedstock chemical composition, and fuel type. To assess the technological capacity in the country, data is required on the availability of technical skills necessary to support bioenergy processing operations, and on both skilled and unskilled labour requirements. With regard to the chemical composition of the bioenergy crop varieties, information is required on: moisture; fibre; total carbohydrate; sugars; fats; starch; oil; ash, etc. In addition, information on local conditions such as income tax, average salaries, and utility charges are needed.

BIOTA is designed for users without specific technical skills/expertise. The user, however, needs to have access to the required data. On the other hand, PENTA requires greater technical skills and is recommended for use by those experienced in industrial engineering.

Determining feedstock production costs requires inputs from local agronomists and agricultural economists, particularly knowledgeable in the crops/feedstocks considered and in both commercial and smallholder farming practices in the country.

LIMITATIONS AND APPLICABILITY TO BIOENERGY

Feedstock production costs represent a significant share of total biofuel production costs. Therefore assumptions regarding the feedstock price at plant gate have a significant impact on the estimated biofuel cost. Feedstock production cost estimates should therefore be based on local agricultural practices and local production cost patterns. The analysis only superficially captures post-harvest production stages and profit margin aspects. These two

aspects need to be better incorporated into the analysis in order to assess profitability under different production conditions in a more accurate manner.

PENTA is run in a commercial engineering process simulator, Aspen Plus, which may not be accessible to all users, due to the cost and/or to the required skills.

As described above, BIOTA has been specifically designed for bioenergy techno-economic analyses. PENTA can be applied to bioenergy production as well (see example below).

EXAMPLE: FAO'S BIOENERGY AND FOOD SECURITY (BEFS) PROJECT: USING PENTA AND BIOTA TO INFORM BIOENERGY POLICY-MAKING IN TANZANIA AND PERU

In *Tanzania*[121], an assessment of the technological capability was done by the FAO's Bioenergy and Food Security (BEFS) project in order to define the most suitable bioenergy processing technologies. The assessment covered three areas: (1) the availability of the human skills that are necessary to support biofuel production; (2) access to services and to technologies in the local markets, and (3) access to processing inputs for the operating biofuel plants. Based on these criteria, three technology options with different levels of complexity were identified for the processing stages. The results highlighted the importance of technology transfer and local capacity building for the long-term sustainability of the national biofuel industry.

In *Peru*[122], the analysis included nine biofuel production scenarios (from sugar cane, palm oil, and jatropha). The analysis that was conducted by the FAO's BEFS project aimed to assess the competitiveness if a portion of the biofuel industry with part of the feedstock supplied by smallholders. The results suggested that including smallholders in the supply chain can, under some conditions, be competitive with liquid biofuel production systems that are purely large scale-based. However, there is a need to strengthen smallholders' bargaining power in order to put them in a condition to benefit from bioenergy development.

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121 For further details on the BEFS analysis in Tanzania, see: FAO. 2010. "Bioenergy and Food Security - The BEFS Analysis for Tanzania". *FAO Environment and Natural Resources Working Paper* No. 35. Rome.

122 For further details on the BEFS analysis in Peru, see: FAO. 2010. "Bioenergy and Food Security - The BEFS Analysis for Peru: Supporting the Policy Machinery in Peru". *FAO Environment and Natural Resources Working Paper* No. 40. Rome.

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Availability: February 2012

Ar	Arabic	F	French	Multil	Multilingual
C	Chinese	P	Portuguese	*	Out of print
E	English	S	Spanish	**	In preparation

The FAO's Bioenergy and Food Security Criteria and Indicators (BEFSCI) project has compiled a set of thirty relevant tools and methodologies that can be used to assess, during both planning and monitoring, the main environmental and socioeconomic impacts of bioenergy. The results can inform the development of a sustainable bioenergy sector and of sustainable operations.

Modern bioenergy development, through its environmental and socio-economic impacts, may have positive or negative effects (both direct and indirect) on the four dimensions of food security: availability, access, utilization and stability.

For instance, bioenergy may create new employment and income-generating opportunities, with positive effects on people's access to food. At the same time, if good practices are not implemented, bioenergy production may lead to negative impacts, for example, on the productive capacity of land or on water availability and quality, with negative repercussions for food security.

In order to ensure that modern bioenergy development is environmentally and socially sustainable and that it fosters rural development and food security, the aforementioned impacts need to be assessed at the national and operator level by the relevant stakeholders, during both planning and monitoring phases.

The thirty tools and methodologies that BEFSCI has compiled can be used to conduct these impact assessments, as well as to inform the development of sustainable bioenergy policies, strategies and investments.

For each environmental and socio-economic dimension addressed by the selected tools and methodologies, an introductory text about the relevance of the dimension considered for food security and how it may be impacted by modern bioenergy development is provided.

For each tool and methodology included in the report under these dimensions, a description is available, covering the following aspects: scope; aims and objectives; methodology and required data and skills; and limitations and applicability to bioenergy. In addition, an example of the application of the tool/methodology in the context of bioenergy (if available) or in the agricultural and energy sectors is presented.