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Assessing the Sustainable Biomass Production for the Bioenergy Market
–
The Case of Jatropha in Peru

Diplomarbeit

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Vorwort

Die vorliegende Arbeit wurde im Rahmen einer Diplomabschlussprüfung (Diplomarbeit) der Leibniz Universität Hannover am Institut für Umweltökonomik und Welthandel und in Zusammenarbeit mit der German ProfEC GmbH erstellt. Die Fragestellung bezog sich auf den Bioenergiemarkt und hier im speziellen auf die Frage, ob eine nachhaltige Produktion und Nutzung der Ölpflanze Jatropha unter bestimmten Bedingungen und in einem speziellen Fall nachhaltig sein kann. Dabei wurden alle drei Nachhaltigkeitskriterien – namentlich ökonomische, ökologische und soziale Kriterien – berücksichtig.

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List of Abbreviations

ACT	Accelerated Technology
AG	Incorporation
AHK	German Chamber of Foreign Trade
AIDS	Acquired Immune Deficiency Syndrome
Apr.	April
Aug.	August
B5	Blend of 5 % biodiesel to conventional diesel
B10	Blend of 10 % biodiesel to conventional diesel
BBC	British Broadcasting Corporation
BCRP	Central Reserve Bank of Peru
Bill.	Billion(s)
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BtL	Biomass to Liquid
C	Celsius, Costs
C.P.	Ceteris paribus
CAN	Andean Community of Nations
CBA	Cost Benefit Analysis
CDM	Clean Development Mechanism
CFC	Common Fund for Commodities
CH_4	Methane
CHP	Combined Heat and Power Plants
Cm3	Cubic Centimetre
CO_2	Carbon dioxide
CONCYTEC	National Council of Science, Technology and Innovation
D. V.	David van der Zaan
Dec.	December
DED	German Development Service
DS	Supreme Decree
E. g.	Example given
E2	Blend of 2 % ethanol to conventional gasoline
E10	Blend of 10 % ethanol to conventional gasoline

E25	Blend of 25 % ethanol to conventional gasoline
EBB	European Biodiesel Board
EEA	European Environment Agency
EJ	Exajoule
EMPA	Swiss Federal Laboratories for Materials Testing and Research
Equiv.	Equivalent
Est.	Estimated
Et al.	And others
ET	Evapotranspiration
ETBE	Ethyl tertiary butyl ether
Etc.	Et cetera
EU	European Union
EU-25	European Union (25 member states)
F.	Following
FAEE	Fatty acid ethyl ester
FAME	Fatty acid methyl ester
FAO	Food and Agricultural Organisation of the United Nations
Feb	February
FN	Footnote
FTA	Free Trade Agreement
FU	Functional Unit
G	Gramme
GAMS	General Algebraic Modeling System
GBEP	Global Bioenergy Partnership
GDP	Gross Domestic Product
Gen.	Generation
GHA	Gigahectare(s)
GHG	Greenhouse gas
GJ	Gigajoule
GMO	Genetically modified organism
GTZ	German Technical Cooperation
H	Hour
Ha	Hectare
HIV	Human immunodeficiency virus

I. e.	That means
IEA	International Energy Agency
IIAP	Research Institute for the Peruvian Amazonia
ILO	International Labour Organisation
INEI	National Institute for Statistics an Informatics
INIA	National Agricultural Research Institute
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
Jan.	January
Jul.	July
Jun.	June
Kg	Kilogramme
Km	Kilometre
L.	Litre
LCA	Life-Cycle-Assessment
LCV	Low calorific value
LDCs	Least Developed Countries
LP	Linear programming
M	Metre
M.a.s.l.	metres above sea level
Mar.	March
Mbpd	Million Barrels Per Day
MEM	Ministry of Energy and Mines
MERCOSUR	Southern Common Market
Mill.	Million(s)
MINAG	Ministry of agriculture
MJ	Megajoule
Mm	Millimetre
Mm^2	Square millimetre
Mr.	Mister
MSW	Municipal Solid Waste
Mtoe	Million tons of oil equivalent
N	nitrogen
N_2O	Nitrous oxide

Na*	Data not found
No.	Number
No.	Number
Nov	November
NPV	Net present value
Oct	October
OECD	Organisation for Economic Co-operation and Development
P.	Page
PEP	Official Site of the Peruvian Government
PES	Primary energy supply
PH	Pondus Hydrogenii
PJ	Petajoule
PMB	The Biofuels Promotion Law
Pp.	Pages
PPO	Pure plant oil
PPP	Public-Private-Partnership
PROINVERSION	Private Investment Promotion Agency – Peru
PEN	Peruvian Soles
R&D	Research and Development
RE	Renewable energy
REN21	Renewable Energy Policy Network for the 21st Century
RME	Rape seed methyl ester
S	Second
Sep	September
SNV	El Servicio Holandés de Cooperación al Desarrollo
SP	Shadow Price
SRU	German Advisory Council on the Environment
SRU/SG	German Advisory Council on the Environment / Special Report
T	Ton(s)
TJ	Tetrajoule
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme

US	United States
US$	US-Dollar
USA	United States of America
Vol.	Volume
VWP	United Workshops for Vegetable Oil Technology
WBSCD	World Business Council for Sustainable Development
WBGU	German Government’s Advisory Council Global Change
WEO	World Energy Outlook
WTO	World Trade Organisation
WWF	World Wildlife Fund
Yr	Year

1 Introduction

Since the beginning of human civilisation, natural resources have been exploited recklessly. Whilst former invasions had mainly been of local impact, since the beginning of industrialisation environmental damage resulting from human actions, particularly greenhouse gas (GHG) emissions to the atmosphere are affecting the global ecosystem. This has led to environmental pollution, the depletion of species, and global warming. During the 20th century global air and ocean temperatures have increased disproportionally, leading to an unequivocal warming of the climate system – the so-called climate change[1] (IPCC (2007a), p. 30). The main causes of climate change are the follwing GHGs: carbon dioxide (CO_2) methane (CH_4), and nitrous oxide (N_2O) – triggered primarily by fossil fuel use. Climate change is aggravated and accelerated by the uncontrolled destruction of natural forests that serve as CO_2 sinks. These developments have led to spacious and temporal modifications in rainfall, an increased global average sea level, and much more frequent and more intense natural disasters (IPCC (2007a), pp. 35 f.). The Intergovernmental Panel on Climate Change (IPCC) estimated an average rise in temperature of between 2 and 6.1 °C from now until the end of the 21st century (IPCC (2007a), p. 67).

Besides, threatening aspects of decreasing energy supply as a consequence of the exploitation of fossil energy sources, revealed by continuously rising prices of crude oil[2] in contrast to a globally growing energy demand, have raised concerns about energy security. Both developments have resulted in the search for alternatives in order to change the currently prevailing global energy matrix that is predominantly based on fossil fuels[3] (MSANGI et al. (2007), pp. 2, 4). Against that background, renewable energy sources, in particular biofuels have attracted increasing attention in recent years. They have been championed as a sustainable energy source that may help to cope with rising energy prices and to increase security of supply, address environmental concerns about GHG emissions, and offer new income and employment opportunities to farmers and rural communities around the world" (HAZELL et al. (2006), DOORNBOSCH et al. (2007), p. 1). In the last couple of years numerous countries have already launched and many more are expected to launch ambitious programmes, as well, in order to

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[1] According to the IPCC climate change "refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity." (IPCC (2007a), p. 30).

[2] At April the 14th, 2008, the crude oil price/barrel is US$ 109.65 (HANDELSBLATT (2008)). An overview about the development of the crude oil price/barrel during the past three years is given in Appendix I (Figure I).

[3] Figure 3 (Section 3.4) gives an overview about the global consumption of total primary energy in 2005.

encourage the production and use of biofuels, amongst them, the United States (US) and the European Union (EU) (REN21 (2008), pp. 27 f.). According to DOORNBOSCH and STEENBLIK (2007), “farmers are ready for action, industry is investing, and governments have opened up their treasuries to help biofuels take off.”

1.1 Problem

Regardless of the potential benefits, a very lively and controversial discussion is being held at the moment with respect to possible risks based on a rapid bioenergy expansion as it is feared that it will possibly result in a difficult trade-off between energy security and the resulting economic profit on the one hand and food security as well as environmental integrity on the other hand (HAZELL (2006a)). Therefore, potential adverse impacts can include the “upward pressure on international food prices, making staple crops less affordable for poor consumers, potentially significant adverse impacts on both, land (soil quality and fertility) and water resources, and on biodiversity and ecosystems in general [, in the worst case even increasing life-cycle emissions of GHGs, D. V.]” (MSANGI et al. (2007), p. 2). Experiences to date have shown that such concerns are justified as the large-scale production of biofuels in Brazil, Malaysia, and Indonesia have already demonstrated tremendous negative social and environmental impacts (GBEP (2007), p. 2, FRITSCHE et al. (2006), p. 15). According to these experiences, economic and environmental benefits of bioenergy such as the reduction in CO_2 emissions have to be viewed against negative ecological effects caused by unsustainable large-scale bioenergy plantations around the world (SCHMITZ (2007), p. 1475), high social costs due to subsidies[4], and decreasing food production.

1.2 Objective

Against the background of an accelerating expansion of bioenergy production and use around the world as well as the remaining uncertainties with respect to the potential benefits and risks, it is of crucial importance to figure out whether the production and use of a certain bioenergy crop in a given case under given frame conditions can actually be designed in a sustainable way and to what extent the respective energy crop can contribute to the intended goals, respectively.

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[4] Currently, in most regions of the world without governmental support biofuel could not be produced at competitive prices (DOORNBUSCH et al. (2007), p. 9).

This study focuses on the small-scale cultivation of the vegetable oil crop jatropha and at times refers to a DED development Project in San Martín, Peru. Jatropha – as it is a perennial crop – is considered to be a promising alternative with respect to environmental risks. An assessment is made on whether the entire production chain of jatropha can be a sustainable covering all three dimensions necessary to be examined, the economic, the social, and the ecological one. In this context, parameters crucial to the establishment of a sustainable biomass production are intended to determine.

This study is basically divided into two parts. The first part is solely based on a literature review and illustrates the current and expected situation of bioenergy – particularly biofuels – production around the world as well as potential problems and risks. According to the objective of this study, in Chapter 2 the concept of sustainability (Section 2.1) is outlined as well as what is understood of a sustainable biomass, in this case bioenergy production (Section 2.2). In order to understand the subject of biomass and its energetic use and to capture its current and possible future importance in its full scope, Chapter 3 gives an overview about the different pathways existing, covering the numerous potential benefits attributed to biomass accompanied by an increased worldwide demand (Section 3.2), the projected contribution to global energy supply by 2050 (Section 3.3) as well as the current status and (expected) future developments of the biofuels sector in particular (Section 3.4). Chapter 4 completes the first part giving a comprehensive overview of environmental, social, and economic key challenges that have to be considered in each case to assess the sustainability respectively establish a sustainable bioenergy production regarding the entire production chain – from feedstock production right up to the final energy use.

By means of a practical example the second part (Chapter 5) picks up the findings resulting from the first one and tries to apply them in order to quantitatively as well as qualitatively assess whether the production of jatropha for the bioenergy market by small-scale farmers in the Peruvian region of San Martín can be established in a sustainable manner. Reference is made to a case in the region of San Martín, Peru. For that purpose Section 5.1 gives a general review of Peru as a country, especially focussing on the agricultural and energy sector, before in Section 5.2 basic information about the Peruvian biofuels sector, in particular, is provided. Section 5.3 starts with a detailed description of benefits and potentials linked to jatropha in order to assess potential environmental (5.3.2) and social (5.3.3) impacts before in Section 5.4 – mainly based on data received by the DED concerning a pilot project currently performed by them (5.4.1) – the financial assessment is performed by means of a mathematical maximisation model using General Algebraic Modeling System (GAMS). Chapter 6 completes the study with a summary of the findings of the previous chapters and final conclusions.

2 Theoretical Background

2.1 The Concept of Sustainability

At least since the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992, the paradigm of sustainability or sustainable development, respectively, has encountered economic science. As its full meaning is very complex and emerging from different dimensions, it is rather difficult to agree upon one uniform definition as the existence of numerous definitions proves.

At its most basic level, the so called Brundtland-Commission defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (UN (1987)).

The concept of sustainable development can further be divided into three constituent components encompassing economic, social, and environmental sustainability. The overarching objectives and essential requirements for a sustainable development are set out by the UN as follows: (a) eradicating poverty, (b) protecting natural resources, and (c) changing unsustainable production and consumption patterns. Thereby, common agreement exists upon the fact, that these three components can not be regarded separately, as they are highly "interdependent and mutually reinforcing pillars" (UN (2005), pp. 11 f).

2.2 Sustainable Biomass Production

"Biomass is basically a stored source of solar energy initially collected by plants during the process of photosynthesis whereby carbon dioxide is captured and converted to plant materials mainly in the form of cellulose, hemi-cellulose and lignin. The term 'biomass' therefore covers a range of organic materials recently produced from plants, and animals that feed on plants. The biomass can be collected and converted into useful energy." (IEA (2007b), p. 13).

Besides significant potential benefits described below (see Section 3.2), biomass production can cause both, negative ecological and social impacts, as well (see Chapter 4), whereby the extent to which externalities occur depends very much on the respective energy crop, cultivation method, conversion technology, and the country or region under consideration (DUFEY (2007), p. 37, KALIES et al. (2007), pp. 127-136).

In compliance with the previously mentioned (see Section 2.1) biomass for the bioenergy market as well as bioenergy itself can only be regarded as a sustainable energy source if its entire production chain – ranging from feedstock production over refining and conversion right up to end use practices – is considered to be sustainable with regard to all three dimensions: the environmental, the social and the economic one (GBEP (2007), p. 2).

While financial benefits and costs are of a direct character and hence, relatively easy to assess by means of mathematical methods – as done in Chapter 5 via Linear Programming –, the appraisal of impacts on environment and society is a very challenging task, as the positive and negative effects outgoing from biomass production are highly intercorrelated and are often underlying intrinsic time-lags. In order to predict the entire ecological impacts of a certain type of biomass a Life-Cycle-Assessment (LCA) has to be employed. The LCA includes production (i. e. the choice of feedstock, agricultural practices, land use changes etc.) refining and conversion processes, end-use practices, and by-products (GBEP (2007), p. 3). None of the currently existing LCA-studies of biomass comply with this synonymously called "from well to wheel" or "from the cradle to the grave" approach. They are rather focussing on different issues, which make a comparison impossible. This is due to the complexity of LCA's on the one hand and the rapid development in practice compared with the pace of research on the other hand (SRU (2007), p. 37). Therefore, as it could be said to be impossible to carry out a final appraisal of the ecological impacts of biomass so far, key ecological impacts along the production chain of bioenergy are discussed below (see Chapter 4), ranging from energy and GHG balances to impacts on soils, water, and biodiversity. In consideration of social risks land use conflicts and matters of food security are of enhanced significance. Concerning both, the evaluation of environmental as well as social impacts of biomass production only tendential statements can be made.

3 Biomass and Bioenergy

Non-Food biomass for energetic and material use is generally distinguished into renewable primary products on the one hand and biogenic residues on the other hand (SRU (2007), p. 4). For each of these categories Table 1 gives an overview of different sources.

Table 1: Overview of the Origin of Biomass

Renewable Primary Products	Biogenic Residues
- Energy Crops: (e. g. Maize, Rapeseed, Sugar Beets, Grasses, Corn, Sun Flower, Cottonwood, Pastures, etc. - Organic Primary Products for material use: Oil Plants, Fibre Plants, Starch Crops) - Growth of Grassland - Forestry-Wood	- Agriculture Residues: Straw, Liquid Manure etc. - Forestry: Small Dimensioned Wood, Forest Residual Wood, etc. - Timber and Paper Industry: Matured Timber and Paper Sludge - Landscape Conservation: Loppings, Pruning etc. - Animal Production: Animal Fats, Slaughterhouse waste - Food & Luxury Food Industry: Mashed Potatoes, Spent Grain, Molasses, Apple Pomace - Waste Industry: Organic Part of Residual Waste, Food Waste, Landfill Gas of Waste Landfill - Sewage Water Industry: Sewage Sludge and Gas

Source: SRU (2007), p. 4.

Before biomass can be used for energetic or material purposes, some stages such as for example, the cultivation and production of the primary products, its provision as well as different processing steps have to be done (see Figure 1). In terms of energetic use biomass can be utilized as a substitute in the three energy sectors of power, heat and fuel generation. Referring to its material use biomass is utilised to produce goods of material nature. Due to the common resource basis of both pathways, they are competing with each other and simultaneously with the food and fodder industry (BRINGEZU et al. (2007), pp. 12, 16, SRU (2007), p. 4). According to the objective of this study the main focus is on the energetic use of biomass, particularly on biofuels.[5]

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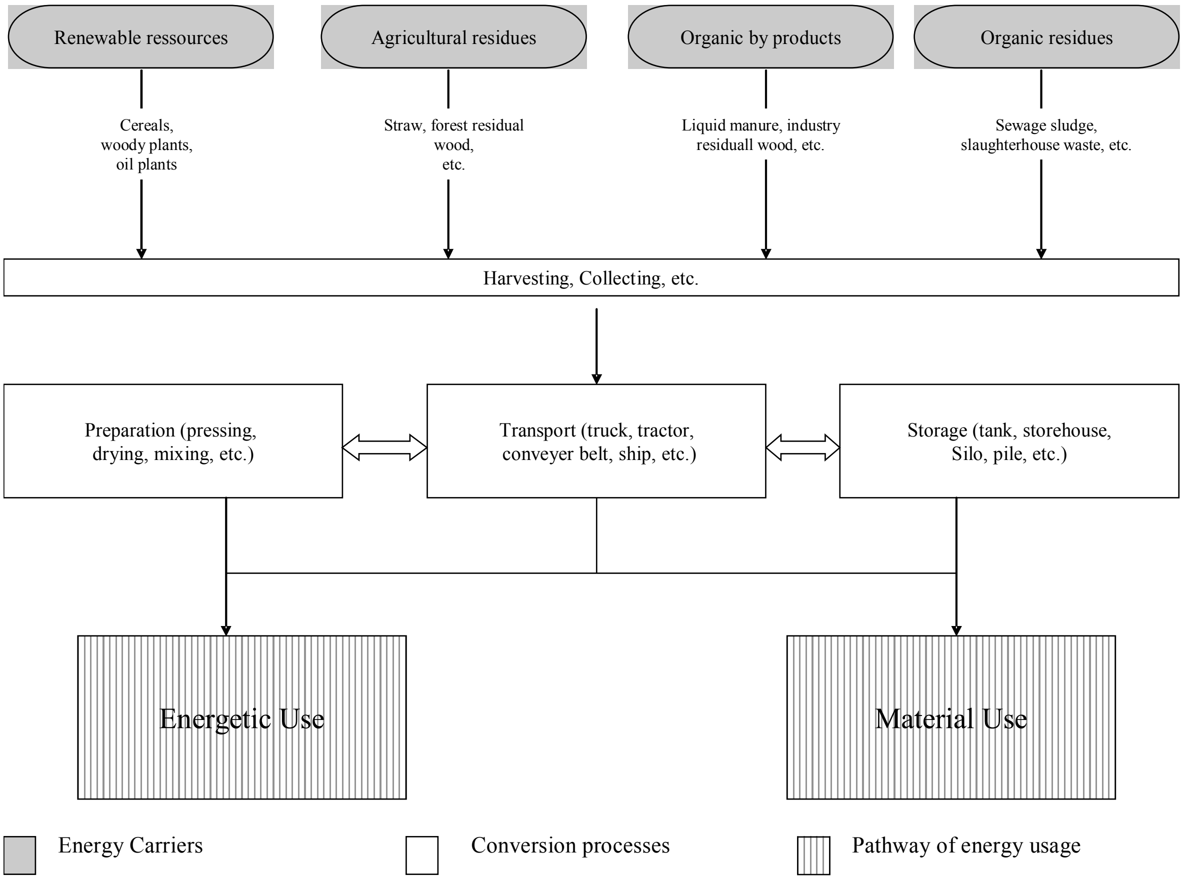
[5] For the sake of completeness, Appendix I (Figure II) contains an overview of different material uses from vegetable feedstocks right up to possible end-uses.

Figure 1: Provision of Biomass and its Usage Possibilities



Source: Kaltschmitt (2006), p. 646.

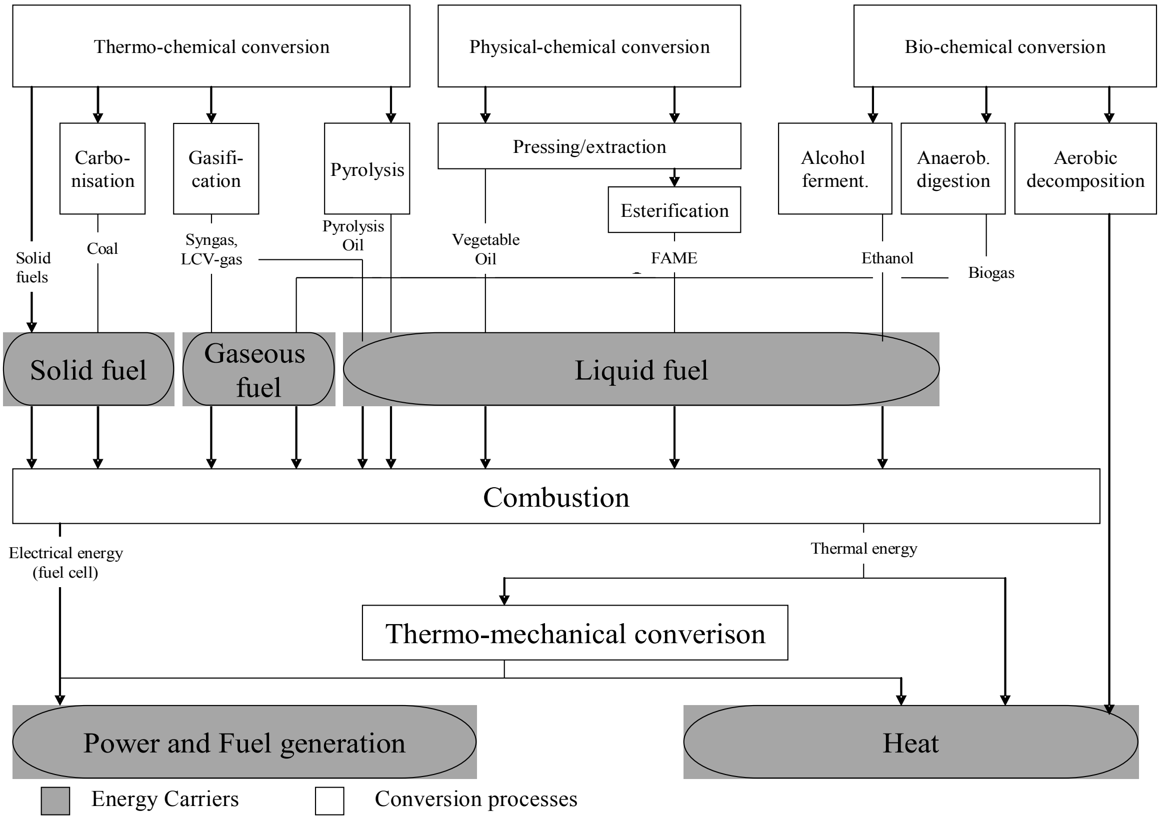
3.1 Energetic Use of Biomass

There are various technologies to produce energy from biomass, whereby three basic methods are distinguished:

- thermo-chemical conversion (e. g. pyrolysis, carbonisation, gasification)
- physical-chemical conversion (e. g. pressing and extraction)
- bio-chemical conversion. (uses e. g. micro-organisms or bacteria)

Except direct combustion and aerobic decomposition the result of all of these conversion processes is a secondary energy carrier either of solid, liquid or gaseous nature. These conversion processes can be regarded as an intermediate level prior to transformation into the preferred final usage. Lastly all secondary energy carriers will be combusted and used for power, heat or fuel generation - this can be in combustions, engines, turbines or, prospectively, also in fuel cells. Hence, theoretically it is possible to completely replace fossil energy carriers by biomass products. Figure 2 illustrates the different conversion technologies and its possible outcomes.

Figure 2: From Biomass to Bioenergy - Conversion Technologies



Source: KALTSCHMITT (2006), p. 646.

Physical-chemical conversion processes – the relevant methods as regards to this study – are based solely on oil seeds (e.g. jatropha curcas, rape seeds, sunflower seeds) and result in liquid energy carriers only. The separation of oil is mainly done by mechanical pressing but can alternatively be done by extraction or even a combination of the two. For energetic purpose the vegetable oil resulting can be combusted either in its pure form or after a chemical conversion (transesterification) to Fatty Acid Methyl Ester (FAME) – also known as biodiesel – in Combined Heat and Power-plants (CHP) and as fuel for engines[6] (KALTSCHMITT et al. (2007), pp. 514 f.).[7]

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[6] To be able to use vegetable oils for engine uses either conventional diesel engines have to be modified or the oil – as already mentioned – has to be chemically converted, mainly because of great differences in viscosity compared to conventional fuels (SRU (2007), p. 6).

[7] For further information concerning the thermo- and bio-chemical conversion, see for example, SRU (2007), p. 6 f.

3.2 Benefits of Biomass and Bioenergy

In recent years biomass as an alternative energy source has drawn a lot of attention in both, developed and developing countries. The predominant factors stimulating the recent and projected global growth of the bioenergy sector is its potential to increase energy security[8], foster rural development, mitigate climate change, and to develop new exports (UN (2007)).

In consideration of continuously rising energy prices, uncertainties with respect to future energy supply, and the need to reduce expenses for energy imports, biofuels as one type of bioenergy have gained increasing importance, as they are expected to diversify and expand the energy matrix and thus, to reduce the dependence on costly imported fossil fuels as well as to increase energy security at the national and the local level (DUFEY et al. (2007), p. 2, HAZELL et al. (2006)).

Furthermore, bioenergy represents a new market for agricultural products, which may help to reduce commodity surpluses and to improve commodity prices (DUFEY et al. (2007), p. 2). Additionally, rural poor could benefit from new employment and greater income opportunities as well as a better access to energy. Altogether, these factors could contribute to foster rural development (GBEP (2007), p. 2, MSANGI et al. (2007), p. 2). This might especially be the case if the processing could be performed on a small-scale (HAZELL et al. (2006)).

In many countries the production of bioenergy, especially biofuels, is viewed as an opportunity within international trade to develop new export markets for their agricultural produce in order to improve their trade balances (HAZELL et al. (2006), UN (2007)). This appraisal seems to be well reasoned as very ambitious biofuel targets, for example of the EU, can only be achieved by means of imports (SRU (2007), p. 60). By taking advantage of climatic conditions as well as lower labour costs, many developing countries could have a comparative advantage on the international bioenergy market (HAZELL et al. (2006)).

Besides economical considerations, a rising awareness of the negative environmental impacts of fossil fuels with respect to global warming caused by GHG emissions and urban air pollution on the one hand as well as international commitments assumed under the Kyoto Protocol on the other hand, have also led to a shift towards the search for (environmentally more friendly) alternatives, especially within industrialised countries (DUFEY et al. (2007), p. 2, UN

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[8] Energy security means “the availability of energy at all times, in sufficient quantities and at affordable prices” (COELHO (2005), p. 5).

(2007)). Against that background bioenergy is an attractive option, as it is a renewable energy source that at the same time has the potential to reduce carbon emissions or at least to slow their growth. This is due to the 'carbon cycle', i. e. its characteristic of only emitting carbon to the air that has formerly been captured during plant growth (Hazell et al. (2006)). In developing countries, the prospect of attracting investments in, for example carbon trading systems such as the Clean Development Mechanism (CDM), is also driving the interest in bioenergy (Dufey et al. (2007), p. 2). Another environmental benefit possibly generated by the cultivation of biomass is the reduction in land degradation especially if perennial crops are planted (GBEP (2007), p. 2)

As shown, there are many reasons that speak on behalf of the production of biomass and its use as a bioenergy. Nonetheless, the very existence of such potentials does not necessarily imply their realisation. As will be seen in Chapter 4, the management with respect to the entire production chain is the crucial factor in order to realise the potential benefits, especially to establish a sustainable development. Table 2 summarises the key benefits of bioenergy.

Table 2: Key Benefits of Bioenergy

Key benefits of bioenergy
• *Sustainability:* a clean and renewable energy source
• *Availability*: bioenergy development can increase access to energy in rural areas
• *Flexibility:* bioenergy can deliver power, heat and transport
• *Energy Security:* bioenergy can contribute to diversifying the energy mix; there are a wide variety of feedstocks (raw material) for bioenergy and all countries can rely on some domestic sources; reduction of costly imported fossil fuels
• *Mitigation of climate change* – bioenergy can significantly reduce greenhouse gas (GHG) emissions and urban pollution compared to fossil fuels
• *Diversification of rural livelihoods* – in the energy sector, and utilising newly available energy services - facilitating rural development
• *Reduction in land degradation:* especially through planting of perennial bioenergy feedstocks
• *Economic Growth:* new export market; attracting investments by carbon trading systems (e.g. CDM)
• *Other*

Sources: own illustration, following GBEP (2007), p. 2, Dufey et al. (2007), p. 2, UN (2007), p. 1, Hazell et al. (2006))

3.3 Global Bioenergy Potential by 2050

Theoretical Potential → Technical Potential → Economic Potential

The global bioenergy potential is distinguished into three different types, the theoretical, the technical and the economic potential. The **theoretical potential** is explained as the physical ceiling of available energy provided by a certain (renewable) resource in a given place at a given time or time period (Kaltschmitt et al. (2006), p. 21, WBGU (2003), p. 48). For example, the total energy globally produced by solar radiation, i. e. via photosynthesis, equals the amount of about 3150 Exajoule[9] per year (Schmidhuber (2007), p. 8). This amount is around seven times as much as the current global energy use, which is assessed to be between 400 (Hazell et al. (2007)) and 479 EJ per year (Staiß (2007), p. 44). However, the photosynthesis potential is rather irrelevant for an assessment of global bioenergy potential as the total exploitation of biomass existing is impossible to achieve due to technical, economical, ecological, structural, and administrative constraints[10] (Schmidhuber (2007), p. 8, Kaltschmitt et al. (2006), p. 21).

Theoretical Potential → **Technical Potential** → Economic Potential

The **technical potential** on the contrary describes the part of the potential theoretically existent which can be made available with respect to the state-of-the-art technology (Fritsche et al. (2004), p. 74), i. e. that can be harvested in practice and be further processed for practical energy use (Schmidhuber (2007), p. 12). Numerous studies – e. g. Berndes et al. (2003), Fischer and Schrattenholzer (2001) – already tried to quantify the global technical potential of biomass and its possible contribution to world energy supply in 2050 of an estimated 850 EJ annually (Schmidhuber (2007), p. 10). The different results vary tremendously. The values calculated are ranging from around 40 to 1100 EJ per year. Even according to the most optimistic study the technical potential is only around one third of the theoretical one described above (Fritsche et al. (2006), p. 8, Hoogwijk et al. (2003), p. 119). The huge differences among the various studies are mainly based on the two most crucial parameters – (1) land availability and (2) yield levels in energy crop production – as these are very uncertain,

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[9] 1 Exajoule (EJ) = 1 Joule * $10^{18} \approx 23.81$ mtoe (million tons oil equivalent); 1 mtoe = 0.042 EJ (Martinot et al. (2007), p. 25).

[10] For example, nearly one third of photosynthesis, or about 1150 EJ/yr, is produced as phytoplankton and other plants in the oceans but these potentials cannot be ‘harvested’ as they are too inaccessible as well as for other reasons (Schmidhuber (2007), p. 8).

and subject to substantially different opinions (BERNDES et al. (2003), p. 1). Other crucial factors determining to what extent biomass can be made available for energy use depend on (3) population growth, economic development, global diet, and thus food demand, (4) the efficiency of food production, and (5) the future development of competing products, like biomaterials, and competing land use types, e. g. other applications of surplus agricultural area and degraded land (HOOGWIJK et al. (2003), p. 131). Table 3 summarises the global bioenergy production potentials for biomass in 2050.

Table 3: Global Bioenergy Production Potentials for Biomass in 2050

Global bioenergy production potentials for biomass in 2050

	Potential (EJ)	**Main Assumptions and Remarks**
Agricultural Residues	15 – 70	Based on estimates from various studies. Potential depends on yield/product ratios, total agricultural land area, type of production system. Extensive production systems require that residues be left, so as to maintain soil fertility; intensive systems allow for higher rates of residue-energy use.
Organic Wastes	5 – 50	Based on estimates from various studies. Includes the organic fraction of MSW and waste wood. Strongly dependent on economic development and consumption, and the uses to which biomaterials are put. Higher values possible by more intensive use of biomaterials.
Dung	5 – 55	Use of dried dung. Low-range value based on current global use; high value reflects technical potential. Utilization (collection) over longer term is uncertain.
Forest Residues	30 – 150	Figures include processing residues. Part is natural forest (reserves). The (sustainable) energy potential of the world's forests is unclear. Low-range value based on sustainable forest management; high value reflects technical potential.
Energy Crops (current agricultural land)	0 – 700 (100 – 300)	Potential land availability 0–4 gigahectares (Gha), though 1–2 is closer to the average.
Energy Crops (marginal land)	60 – 150	Potential maximum land area of 1.7 Gha low productivity is 2–5 dry tons/ha/yr
Total	40 – 1100 (250 – 500)	Pessimistic scenario assumes no land for energy farming, only use of residues; optimistic scenario assumes intensive agriculture on better quality soils. ( ) = most realistic in a world aiming for large-scale bioenergy use.

Source: own illustration, following FRITSCHE et al. (2006), p. 8.

Looking at the most optimistic scenario bioenergy is assessed to be able to supply more than double the current global energy demand without competing with food production, forest-protection efforts and biodiversity. On the contrary, following the most pessimistic appraisal in 2050 bioenergy will contribute even less to the total energy use as it does today (FRITSCHE et al. (2006), p. 9). Regardless of the widely varying results, at least all studies agree upon the assumption that the non-OECD countries' will account for the lion's share of the technical potential – with Africa and Latin America having the most potential (e. g. SMEETS et al. (2004), pp. 2 f., DOORNBUSCH et al. (2007), p. 14, SCHMIDHUBER (2007), p. 12, FRITSCHE et al. (2006), p. 9).[11]

Theoretical Potential → Technical Potential → **Economic Potential**

However, the technical potential needs to be scaled down to that part of the bioenergy stock that can after harvesting, transport and processing – at a given time and under given economic frame conditions – compete with the existing alternatives, in order to calculate the **economic potential** (SCHMIDHUBER (2007), p. 13, WBGU (2003), p. 48).[12]

The only study estimating an economic potential of biofuels in 2050 has been done by FISCHER and SCHRATTENHOLZER (2001). According to this analysis, in 2050 the global technical potential of bioenergy from biomass is assessed to be around 400 EJ per year, while its annual economic potential will be 158 EJ and furthermore, only roughly one third – 53 EJ – will annually be used for biofuels (SCHMIDHUBER (2007), pp. 7-14)[13] compared to an estimated annual consumption of 850 EJ worldwide.

3.4 Status Quo of Biofuels Worldwide

In the last 32 years the world's total primary energy consumption almost doubled from roughly 257 EJ[14] in 1973 to around 479 EJ in 2005[15] (IEA (2007), p. 6), to which renewable energy added 12.5 % and 12.7 %, respectively. Although in the course of various climate change commitments since 1990 an increasing significance has been attributed to renewable energy sources, in order that up until 2005 the absolute supply has annually gown by approx-

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[11] For example, according to projections of SCHMIDHUBER (2007) non-OECD countries will account for 80 % of the technical bioenergy potential in 2050 which will correspond to 320 EJ in his projection (SCHMIDHUBER (2007), p. 10).

[12] Thereby, the production costs of bioenergy are of course a crucial factor besides the price of fossil energy. Between 50 and 80 % of bioenergy production costs are dedicated to feedstock costs alone while the remaining part is split up to transport and processing. Further development of agricultural feedstocks and technological innovations regarding harvesting and converting are therefore of crucial importance (SCHMIDHUBER (2007), pp. 13-14, DOORNBUSCH et al. (2007), p. 18).

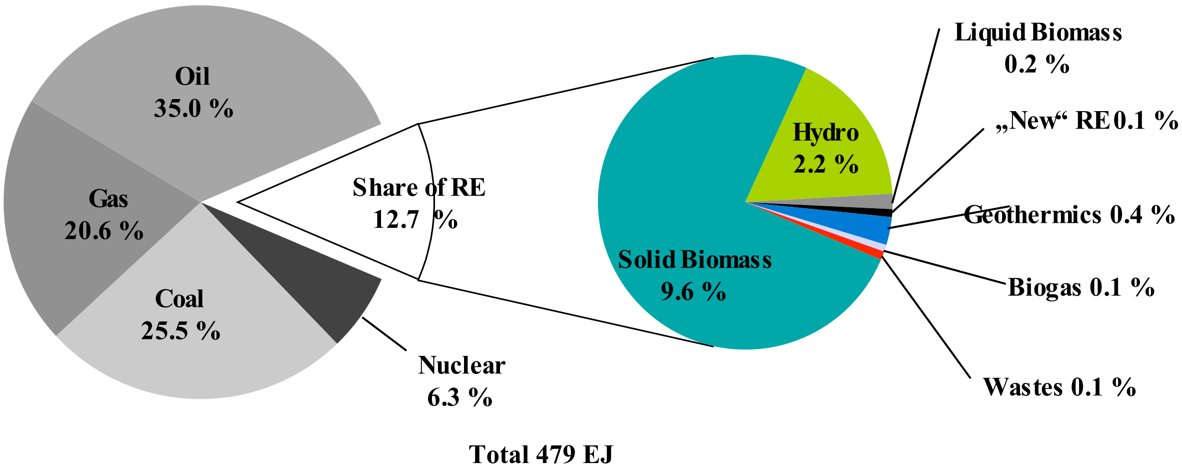
[13] For comparison only, in 2004 only 0.01 Gha was used for the production of biofuels (DOORNBUSCH et al. (2007), p. 13) which equaled to an amount of 0.9 EJ in terms of primary energy provided by biofuels in the same year. Both figures refer to a global scale perspective. The total bioenergy from biomass provided is currently around 46 EJ. This equals 10 % of the total current world primary energy consumption, but with more than two thirds used as traditional biomass in developing countries (IPCC (2007), p. 276). Especially the poor heavily rely on the use of traditional biomass – such as the combustion of wood and agricultural residues. This causes significant negative impacts to human health due to indoor pollution as well as this kind of biomass use puts a strong pressure on local resources (DE LA TORRE UGARTE (2006)).

[14] 1 Petajoule = $1\ \mathrm{EJ} * 10^{-3} = 1\ \mathrm{J} * 10^{15} \approx 0.024$ mtoe.

[15] Figure 3 illustrates the global consumption of total primary energy in 2005.

imately 1.8 %, during this period the contribution of renewable energy carriers has almost stayed constant at around 13 %. This means that the amount of renewable energy has grown proportionally to total energy consumption (IEA (2007), p. 6, IEA (2007a), p. 3, STAIß (2007), pp. 44 f.)[16], mainly caused by a steady rise in energy demand in developing and transition countries, e. g. India and China, where lower environmental standards are applied (IEA (2007c), p. 3).

Figure 3: Global Consumption of Total Primary Energy in 2005



a “new” RE = Solar, Wind and Tide energy

Source: STAIß (2007), p. 44.

Looking at the structure of renewables according to their kind of use solid biomass is by far the leader with a share of 9.6 % of global primary energy supply. This circumstance is due to its widespread traditional use. Solid biomass is followed by hydro and geothermal power with a share of 2.2 % and 0.4 %, respectively, to world primary energy supply. Liquid biomass, which comprises, for example, ethanol, methanol, and vegetable oil, contributes 0.2 %[17] and the last positions are taken by the so called “new” renewables (i. e. wind, solar and tide energy), biogas and wastes, each accounting for roughly 0.1 % of world primary energy supply (STAIß (2007), p. 44).

Within the global primary energy supply through renewables biomass accounts for around 78.6 % (of which 75.6 % accounts for solid biomass), hydro (power) accounts for 17.4 % and geothermal, wind, solar and tide energy together account for 4.1 % (STAIß (2007), p. 46). Table 4 gives a short summary of the renewables` share of world primary energy supply.

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[16] In 2005 both, the global demand for energy as well as the absolute renewable energy consumption increased by about 3 %, i. e. by 12 and 2 EJ, respectively (STAIß (2007), p. 44, IEA (2007a), p. 3).

[17] 0.2 % of liquid biomass corresponds to around 958 PJ.

Table 4: Share of Renewables to World Primary Energy Supply 2005

	PES	RE	Share of RE	Share of Biofuels	Share of the most important RE of the entirety of RE (%)		
	(PJ)	(PJ)	(%)	(%)	Hydro	Biomass/ wastes	Others[1]
World	479.103	60.610	12.7	0.2 (958PJ)	17.4	78.6	4.1

[1]Geothermal, solar, wind and tide energy

Source: own illustration, following STAIß (2007), p. 46.

3.4.1 Global Biofuel Production

In recent years global biofuel production has increased continuously (see Figure 4). For the following, the mention of biofuel refers to biodiesel and ethanol only[18], as they account for more than 90 per cent of global biofuel usage (DUFEY (2006), p. 3).[19] While biodiesel – either in its pure form or blended with conventional fuels – is used as a fuel for diesel-powered vehicles based on oil seed crops or other vegetable oil sources[20], such as waste cooking oil, ethanol is typically made of sugar cane[21], corn, or wheat and serves as a substitute for gasoline (REN21 (2008), p. 45). In 2006 around 45 billion litres of biofuel were produced[22]. Alone in 2006, this means an increase of nearly 22 % compared to 2005 when production was around 36.5 billion litres. With around 4 % the contribution of biofuels to road transportation fuels – whose demand equals 1,300 billion litres per year – still remains relatively low (REN21 (2008), pp. 6, 8). As can be current projections forecast a (fast) growing share of biofuel to total energy supply.

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[18] Regarding the energetic use of biomass as biofuel and the respective technologies available one can distinguish between biofuels of the first and the second generation. The production of first generation biofuels is based solely on the utilisation of some parts of agricultural crops - such as the fruits, the seeds, and the stems – as well as on conventional technical processes. Thereby, only saccharid, starchy, and oleiferous crops and fruits are used (ARÉVALO et al. (2007), p. 7). The technologies used for second generation biofuels are currently being tested and demonstrated, but are not expected to become commercially available before 2010 and 2015 at the soonest. Most prominent exponents are the production of ethanol from lingo-cellulose feedstock as wood or straw and the Fischer-Tropsch conversion of solid biomass to a synthetic fuel (Biomass-to-Liquid (BtL) (BRINGEZU et al. (2007), p. 14). Based on this fact the thesis is only taking into consideration first generation biofuels.

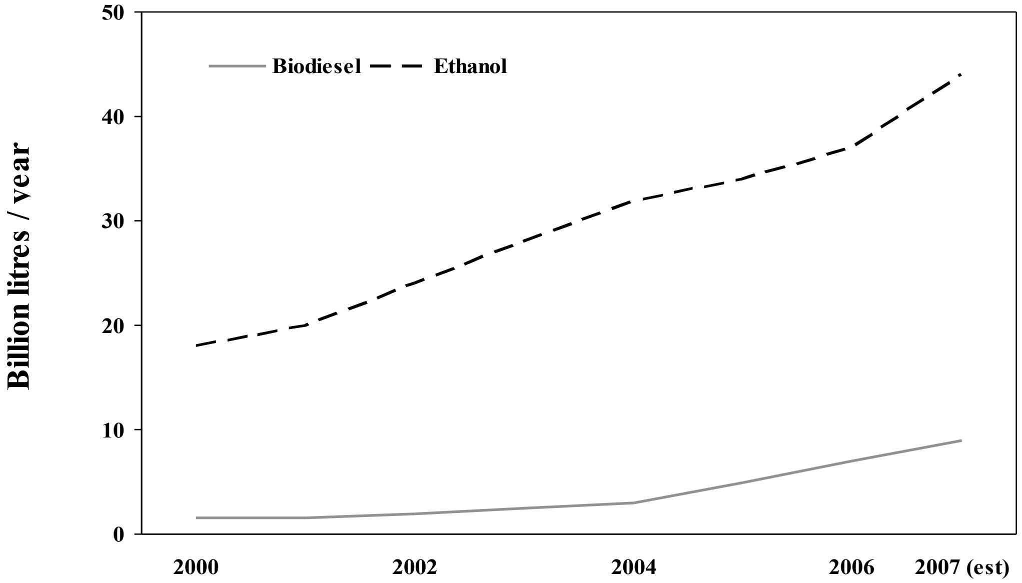
[19] Appendix (Table I) gives an overview different types and technologies to generate biofuels (1st generation)

[20] Most common is the use of vegetable oils as for example rape-seed, palm-oil, soybean, jatropha and others (EASTERLY et al. (2006), p. 3).

[21] Around 60 % of global ethanol production comes from sugar cane (DUFEY (2006), p. 5).

[22] Therefore, 14 million hectares of land were used – i. e. roughly 1 % of the world's available arable land (IEA (2007a), p. 15)

Figure 4: World Biodiesel and Ethanol Production, 2000 – 2007



Source: REN21 (2007), p. 3.

1.1.1.1 Global Ethanol Production

Ethanol is by far the most widely used biofuel for transportation worldwide. Between 2000 and 2006 global ethanol production more than doubled. In this time period ethanol production worldwide increased from almost 18 billion litres in 2000 to around 39 billion litres in 2006 (see Figure 4). This means a rise of about 120 % (MURRAY (2005), REN21 (2008), p. 13).

In 2006 global ethanol production increased from 33 billion litres in 2005 to 39 billion litres, a jump of 18 % (REN21 (2008), p. 13). In that year the US ethanol production increased by about 20 % and has overtaken Brazil as the world's bioethanol production leader for the first time. Both countries still remain by far the dominant producers worldwide (BALAT (2007), p. 201, REN21 (2006), pp. 5 f.). Within the EU, ethanol production increased by 70 %, from 913 to 1,565 million litres (LEBENSMINISTERIUM ÖSTERREICH (2007), p. 1). However, compared to the US and Brazil the production levels still remain very low. Table 5 shows the production levels of the top 10 producers of ethanol in 2005 and 2006.

Table 5: Fuel Ethanol Production – Top 10 Countries plus EU

Fuel Ethanol Production 2005/06 - Top 10 Countries plus EU (in billion litres)		
Country	**2005**	**2006**
United States	15	18.3
Brazil	15	17.5
China	1.0	1.0
Germany	0.2	0.5
Spain	0.3	0.4
India	0.3	0.3
France	0.15	0.25
Canada	0.2	0.2
Colombia	0.2	0.2
Sweden	0.2	0.14
EU Total	0.9	1.6
World Total	33	39

Source: REN21 (2008), p. 39, REN21 (2006), p. 22.

3.4.1.2 Global Biodiesel Production

Biodiesel production started in 1991. Since its beginning it has been increasing steadily. Between 2000 and 2005 the production capacities on average grew by 32 % per year (GUBLER (2006)). Up until 2006 they even increased by almost 50 %, from 3.9 in 2005 to 6 billion litres (see Figure 4; REN21 (2008), p. 8). The EU is the global dominant leader in both, production and consumption of biodiesel, whereby Germany accounts for more half of the production with approximately 2.7 million tons.[23] Within the EU, biodiesel production increased from 3.2 in 2005 to 4.9 million tons in 2006, a rise of about 54 % (EBB (2008)).[24] For comparison, the US as the world's second largest producer tripling its production in the same period in 2006 only delivered around 0.85 billion litres of biodiesel (REN21 (2008), p. 14). Table 6 gives an overview of the top 10 biodiesel producers by country.

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[23] Germany is followed by France and Italy producing in 2006 743,000 and 447,000 tons, respectively.

[24] From 2004 to 2006 the number of European countries producing biodiesel has nearly tripled. 27 states are now producing biodiesel on a commercial scale compared to eleven countries in 2004 (EBB (2008)).

Table 6: Biodiesel Production – Top 10 Countries plus EU

Biodiesel Production 2005/06 - Top 10 Countries plus EU (in billion litres)

Country	2005	2006
Germany	1.9	2.80
USA	0.25	0.85
France	0.6	0.63
Italy	0.5	0.57
Czech Republic	0.15	0.15
Spain	0.1	0.14
Malaysia	-	0.14
Poland	0.1	0.13
United Kingdom	-	0.11
Brazil	-	0.07
EU Total	3.6	4.5
World Total	3.9	6

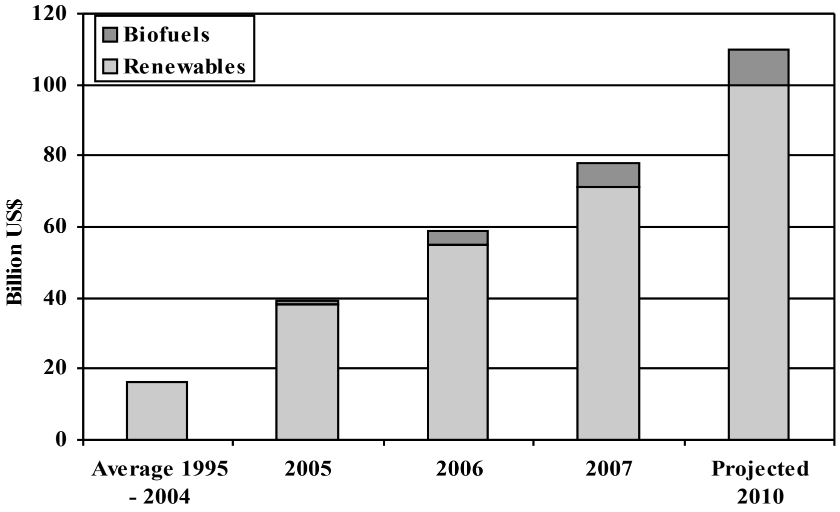
Source: REN21 (2008), p. 39, REN21 (2006), p. 22.

After more than a decade of development and commercial use in Europe, biodiesel has now proved its value as a fuel for diesel engines. Furthermore, the massive increase in the production of biodiesel is expected to continue in the near future (BOURNAY et al. (2005), p. 1). For 2007 the EBB forecasts that production capacity will have reached 10.3 million tons (EBB (2008)).

3.4.2 Investment Flows

Renewable energy has obviously become popular throughout the world. Recent investment flows provide clear evidence of this fact. While between 1995 and 2004 the average global annual investment was about US$ 15 billion, it was already US$ 38 billion in 2005 and further increased to US$ 55 billion in 2006 (ROTHKOPF (2007), p. 1, REN21 (2007), p. 4, REN21 (2008), p. 16). Figures unconfirmed, state that in 2007 investments in renewable energy would be about US$ 71 billion (REN21 (2008), p. 16). Figure 5 illustrates the investment flows of renewable energies and, in particular, of biofuels between 1995 and 2010. According to ROTHKOPF investment in renewable energy will have exceeded the milestone of US$ 100 billion at the latest in 2010 (ROTHKOPF (2007), p. 1).

Figure 5: Annual Investment Flows in Renewable Energy and Biofuels, 1995 - 2010



Source: ROTHKOPF (2007), p. 1 f., REN21 (2008), p. 16, MARTINOT (2008a).

Investments in biofuels in 2005 exceeded US$ 1 billion for the first time (ROTHKOPF (2007), p. 1). For 2006 the figure was already around US$ 4 billion (MARTINOT (2008a)).[25] The value alone of biofuel plants currently being constructed or announced to be built until the end of 2009 in the US, Brazil, and France will be around US$ 10 billion (REN21 (2008), p. 14).[26]

3.4.3 Global Biofuel Policies

In 2004 the number of countries with policy goals or specific targets in terms of renewable energy was 44, whereas in 2007 this figure is said to have already increased to at least 66 countries – including all member states of the EU[27] (MARTINOT (2008), REN21 (2006), p. 3). With regards only to the national level biofuel sector policies nowadays can be found in 53 countries, states, or provinces[28] compared to 22 in 2004 (REN21 (2006), p. 3, REN21 (2008), p. 8). Additionally the EU has set out a uniform policy target for all its 25 member countries (see below).

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[25] Jobs worldwide in renewable energy manufacturing, operations, and maintenance in 2006 exceeded 2.4 million, including some 1.1 million for biofuels production (MARTINOT (2008).

[26] Thereby the USA and Brazil are each accounting for US$ 4 billion, whilst France accounts for US$ 2 billion.

[27] Appendix I (Table II) contains a list of countries having set biofuel policies.

[28] These are 13 Indian states/territories, nine Chinese provinces, nine US states, three Canadian provinces, two Australian states, and at least 17 countries at the national level (REN21 (2008), p. 27).

The targets are mainly achieved by direct control mechanisms and complemented by tax or subsidy incentives. In the case of direct control the most widespread practice is 'mandatory blending'. In that case the government chooses either a certain percentage or a certain amount of biofuels which has to be added to conventional fuels (RAJAGOPAL et al. (2007), p. 106) Table 7 gives an overview of possible policy options.

Table 7: List of Policy Tools and some Examples

Type of policy	**Some examples**
Incentive – Tax or Subsidy	Excise tax credit for renewable energy, Carbon tax, Subsidies for flex fuel vehicles, Price supports and deficiency payments, Tariffs or subsidies on imports/exports
Direct control	Renewable fuel standards, Mandatory blending, Emission control standards, Efficiency standards, Acreage control, Quotas on import/export
Enforcement of property rights and trading	Cap and trade
Educational and informational programs	Labelling
Improving governance	Certification programs
Compensation Schemes	Payment for environmental services

Source: RAJAGOPAL et al. (2007), p. 105.

In the following some examples of existing biofuel policies are given[29], i. e. for the EU, Brazil, and the USA, as they are key players on the biofuel market.

The EU set the goal that by 2010 biofuels have to account for at least 5.75 % of the caloric value of all transportation fuels introduced. The EU member states can decide autonomously how to reach this target (EU (2003), p. 4). Eight countries implemented a tax exemption (REN21 (2006), p. 11).[30] In 2007 the European Commission has extended the objective value up to 10 % by 2020 (REN21 (2006), p. 11).

In the US annually at least 28 billion litres of biofuels and 1 billion litre of cellulosic ethanol have to be blended with conventional fuels by 2012 and 2013, respectively (RAJAGOPAL et al. (2007), p. 106). This target is complemented by a tax credit of US$ 12 cent per litre of mixed biodiesel until 2008 (REN21 (2006), pp. 10 f.). In 2007 the USA decided to extend this objective to at least 136 billion litres per year by 2022 (REN21 (2008), p. 28).

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[29] See Fn 28.

[30] These are namely France, Germany, Greece, Ireland, Italy, Spain, Sweden and Great Britain.

In Brazil a 25 % blending of ethanol has already been in place for a long time. Since the beginning of 2008 it is mandatory by law to blend 2 % of biodiesel with traditional fuels. From 2013 onwards this percentage will be increased to 5 % (REN21 (2006), p. 12). The biofuel policy of Brazil includes a range of support policies, such as retail distribution requirements, production subsidies, and tax preferences for ‘flex-fuel’ cars and those vehicles that run on pure ethanol (REN21 (2008), p. 28).

3.4.4 Projections of Future Biofuel Production Worldwide

A comprehensive review of ten studies regarding a realistic future contribution of renewables to primary energy supply until 2050 has been done by MARTINOT et al. (2007). According to these global scenarios the total amount of primary energy needed by 2050, lies within the range of 600 to 1600 EJ. The share of renewables is projected to vary between 70 and 600 EJ, whereby biofuels account for between 3 and 25 % (MARTINOT et al. (2007), p. 10).

The IEA undertook two studies on this topic in 2004 and 2006, respectively. Within the first study the IEA projects an ethanol production of about 120 billion litres per year or 3 % of all road transportation fuels by 2020. In the same time frame the projected annual biodiesel production is assessed to be around 25 billion litres. Thereby respective policies are assumed to accelerate around the globe (IEA (2004), p. 168). In the framework of the latter appraisal based on the reference share of 3 % two different scenarios are considered, (a) the “ACT” (Accelerated Technology) scenario – which is characterized by aggressive policy intervention, energy intensity reductions, and technology cost reductions by means of deployment and learning and (b) the “TECH Plus” scenario, that comprises even higher technology progress for renewables, nuclear, hydrogen fuel cells, and advanced biofuels. The projected shares of biofuels to total road transportation fuels account for 13 and 25 %, respectively (IEA (2006a), pp. 2-8). The World Business Council for Sustainable Development (2005) calculated some 15 % by 2050 (WBCSD (2005), p. 9). In many scenarios by 2020 second generation biofuels are considered as well, but only with further technology development. Improvements in pretreatment and enzyme cost reductions are considered as necessary to commercialisation (MARTINOT et al. (2007), p. 18).

4 Key Challenges for a Sustainable Bioenergy Production

The prevailing opinion considers the production of biofuels as not sustainable at the most. Assuring the sustainability of a certain production chain – i. e. the production of a specific type of bioenergy based on a specific biomass feedstock – the following aspects tabulated by Table 8 have to be taken into account:

Table 8: Key Challenges of Bioenergy

Key challenges of bioenergy
• *Environmental, social, and economic matters have to be considered* • *food security has to be safeguarded, i. e. it has to be ensured that the increased demand for biofuels does not adversely affect the hungry* • *biodiversity has to be protected* • *competition for land and water has to be managed* • *air, water, and soil pollution has to be controlled* • *barriers to biomass and bioenergy trade have to be removed*

Source: own illustration, following GBEP (2007), p. 2.

4.1 Environmental Impacts

4.1.1 Energy Balance

In the world of physics energy balance is defined as the "arithmetic balancing of energy inputs versus outputs for an object, reactor, or other processing system; it is positive if energy is released and negative if it is absorbed."(NO AUTHOR (2008), p. 1) In regards to bioenergy the energy balance is positive, if the energy required to produce a certain amount of biofuel along the entire production chain is less than its caloric value (DUFEY (2006), p. 39).

Although biomass is defined as a "renewable" resource of energy, biomass production as well as its processing into a usable biofuel requires the consumption of other energy sources, such as fossil fuels (KARTHA (2006), p. 1). Employing the "well-to-wheels" approach, estimates of the energy balance are to consider this energy consumption during the production process as well as potential paybacks due to resulting by-products (e.g. seed cake, glycerine, bagasse, husks, etc.) respectively their energetic counter-values economized (DUFEY (2006), p. 40).[31]

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[31] Typical co-products include animal feed, glycerine, seed cake, fruit husks, and co-generated electricity just to mention a few. For example, if the seed cake is utilized as fertilizer less fertilizer has to be produced, thus energy for processing is saved.

As already indicated, the amount of fossil fuel used varies according to the type of biomass used and the production method applied[32] (KARTHA (2006), p. 1).

With respect to feedstocks annual crops generally have higher energy requirements compared to perennial crops as they demand a greater use of machinery and higher levels of chemical additives. For example, some biofuels from perennial crops such as poplar, sorghum and switchgrass if grown in temperate climates result in energy ratios (i. e. the quantity of useful bioenergy produced per unit of fossil fuel consumed) in the range of 12 to 16 units. These figures can even improve, if cultivation is done in tropical climates with abundant rainfalls – leading to both, higher yields and less energy requirements due to more labour-intensive agricultural practices being applied (KARTHA (2006), p. 1). Energy ratios of annual crops, on the other hand, can be much lower. E. g. Brazilian ethanol from sugar cane – which is viewed as one of the most energy efficient forms of ethanol – has an average energy ratio of 8.3 units, estimates with respect to the energy ratio of wheat-based bioethanol in the EU range between 0.81 and 1.03 units, whereas results for rape based biodiesel showed a ratio even below 1 unit of 0.33 to 0.82 units (DUFEY (2006), p. 40, KARTHA (2006), p. 1).

Differences in energy ratios suggest that the use of those crops is preferable as they offer the best energy balances as compared to crops with lower ratios (DUFEY (2006), p. 41). However, due to political incentives biofuel markets do not necessarily develop in favour of these crops. This is an interesting fact, as the highest levels of domestic agricultural support exist in industrialised countries while the crops with the best energy potential are grown in tropical developing countries.

4.1.2 Greenhouse Gas Emissions

A major advantage associated with bioenergy is the ability to reduce greenhouse gas (GHG) emissions, thus to help mitigate climate change, since its use is carbon neutral[33] (FRITSCHE et al. (2006), p. 18). However, a comprehensive analysis requires the inclusion of all GHGs, such as nitrous oxide (N_2O) emitted in significant amounts in the context of fertilizer and pesticide production and application. Moreover, every single step within the bioenergy production chain – from cultivation over downstream processing right up to storage and trans-

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[32] Fuels can be consumed by farm machinery in land preparation, planting, tending, irrigation, harvesting, storage, and transport; fossil feedstocks for chemical inputs such as herbicides, pesticides, and fertilizers; and energy required for processing the bioenergy crop into a usable biofuel as mentioned above

[33] Only the carbon dioxide which has been absorbed during plant growth is again released to the atmosphere (FRITSCHE et al. (2006), p. 18).

portation – requires is linked with fossil energy consumption and therefore, with additional GHG release (SRU (2007), p. 40).

Another meaningful factor to assess the overall GHG balance from bioenergy supply refers to the effective use of by-products resulting from bioenergy conversion and processing, which could partially offset the GHG emissions caused by the cultivation (FRITSCHE (2006), p. 18).

Furthermore, land use changes for the cultivation of bioenergy crops can have a tremendous impact on the GHG balance, besides the subsequently following production system (annual or perennial, extensive or intensive cultivation) highly depending on the type of land replaced. Estimations assume that the GHG emissions caused by the clearance of natural forest and displacement by energy crops will at least take around 45 years to be offset (KARTHA (2006), p. 2, FRITSCHE et al. (2006), p. 18).[34] If, additionally, social and environmental issues, such as the reduction in forest habitats meaning a threat to species that inhabitat these unique ecosystems and diminishing other important environmental services from forests, are taken into account, there can be no justification for any carbon benefits from bioenergy crops (GBEP (2007), p. 2, KARTHA (2006), p. 2). On the other hand, if a bioenergy crop plantation replaces degraded land, the land could benefit from revegetation. The carbon fixed by the new plants will be higher than compared with the former land type use, also including the carbon in the soil and other below-ground biomass. In the latter case a land use change could not only be beneficial by displacing fossil fuels, but also carbon and other ecosystem benefits can result (KARTHA (2006), p. 2).

A comparison of GHG balances of different paths of biomass use proved that heat and power can potentially be provided with the highest GHG savings (KALIES et al. (2007), p. 132). By assessing the potential to reduce GHG emissions the reference system considered is crucial. In case that a CO_2-intensive technology is replaced, as for example the use of coal, savings are most effective. Thereby the GHG savings potential of biomass is three times as high as that of current biofuels (SRU (2007), p. 53). The potential of liquid biofuels to save GHG emissions, on the other hand – as already mentioned – varies by region, technology and feedstock. Brazilian ethanol is currently producing the largest savings with up to 90 % of GHG emissions compared to fossil fuels. In the case of maize-based ethanol the achieved savings are far lower. They are estimated to be around 13 % (FARRELL et al. (2006), pp. 506-508). In a study

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[34] Another study, undertaken by SCHMITZ (2007) estimates a recovery period of 30 years (SCHMITZ (2007), p. 1475).

published by KALIES et al. (2007) in Germany biodiesel is saving up to 54 % of GHG emissions compared to mineral-oil-based diesel. The use of B5 (5 % blending of biodiesel to diesel) or B10 (10 % blending) is saving 3 and 6 % of GHG emissions, respectively (KALIES et al. (2007), p. 132).

4.1.3 Impacts on Soil

Depending on the type of cultivation method applied as well as the respective bioenergy crop itself – as the numerous possible feedstocks differ from each other concerning criteria like annuity or perenniality and yield as well as water, fertilizer and pesticide use – the ecological impacts on the soil can vary greatly (SRU (2007), p. 42).

The overuse of irrigation, agrochemicals and heavy harvesting equipment can cause eutrophication of habitats, acidification of soils, increased emissions of nitrous oxide (N_2O) and methane. Thus, it contributes to the reduction in fertility of the soils. Additionally, soil erosion and degradation can be intensified even more due to field enlargement and the inappropriate use of machinery (SRU (2007), p. 51, FRITSCHE et al. (2006), p. 19). On the other hand, if managed appropriately, bioenergy cultivation could improve soils, reduce erosion, increase soil carbon, and even help to reclaim degraded land for sustainable use. Especially perennial crops are qualified to do so, as they establish year-round soil coverage (FRITSCHE et al. (2006), p. 19). In general, it can be noted that perennial compared to annual biomass crops are having less negative effects on the soil due to a lower demand of treatment (EEA (2006), p. 15).

Potentially decreasing the advantageousness of biomass production, it is to be mentioned, that the collecting of agricultural and forestry residues (e.g. straw, wood thinnings) as energy carriers could cause a reduction of humus creation and soil carbon as well as nutrient exports, which would contribute to a decline in soil fertility and structure and thus, to erosion and degradation (FRITSCHE (2006), p. 19, KARTHA (2006), p. 2), accompanied by a faster water run off, a loss of habitat and negative impacts on GHG sinks (RODE et al. (2005), pp. 23, 115).

4.1.4 Impacts on Water

The cultivation of water-intensive bioenergy feedstocks, such as short rotation crops like poplars or willows, can cause serious environmental problems being the greater the larger the scale and the dryer the location is (SRU (2007), p. 43). The result can be a water shortage, with the lowering of water tables and water levels in rivers and lakes. The consequence of increased water abstraction include salinisation, the loss of wetlands and the disappearance of habitats by the creation of dams and reservoirs, the drying-out of rivers and a shortage in local water supply (EEA (2006), p. 15).

In addition to the potential conflicts concerning the amount of water required for irrigation, ground and surface water supplies could be contaminated by agrochemicals (fertilizers, pesticides, fungicides) which are applied during the stage of cultivation. The consequences can be: a degraded water quality, effluent run-off problems, and – in some cases – negative impacts on downstream ecosystems (FRITSCHE et al. (2006), p. 19, DUFEY (2006), p. 45). Besides these ecological problems some biomass crops, for example sugar cane, are in direct competition with food crops for irrigation water (KARTHA (2006), p. 2).

4.1.5 Impacts on Biodiversity

The cultivation of bioenergy crops can affect biodiversity tremendously. The greatest threat to biodiversity associated with increased biomass production refers to the expansion of the agricultural frontier, as there already is an intensive competition for land between agriculture, forests and urban uses (DUFEY (2006), p. 44). This would mean “the loss, fragmentation and degradation of valuable habitats such as natural and semi-natural forests, grasslands, wetlands and peat lands and other carbon sinks, their biodiversity components and the loss of essential ecosystem services” (UNEP (2007), p. 36).[35] Moreover, instead of a reduction of GHGs, forest conversion will cause multiple emissions than can be fixed by any energy crop plantation (see Section 4.1.2). Once having converted forest into agricultural area, the question for the applied cultivation method arises. Shifting from a diverse to an intensive cultivation and monocultures, the variety of natural species as well as the typical local agro-biodiversity is reduced (SRU (2007), p. 48).

In the course of an increased biomass use the incentive to use decumbent or standing dead wood is more attractive in the future. As these woods are crucial to many endangered species

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[35] The worldwide growing interest in biofuels has already led to the replacement of tropical forests by palm oil and soy oil plantations in Malaysia and Indonesia, and in Brazil, respectively, in order to produce biodiesel (FRITSCHE et al. (2006), p. 15, GBEP (2007), p. 2). Moreover, Malaysia and Indonesia plan to increase their biodiesel production annually by 248 % respectively 143 % until 2012 (BRAUN (2007), p. 9).

in the forest, serving as a refuge, using these woods would mean a further reduction of biodiversity (SRU (2007), p. 48). Furthermore, the foliage contains nutrients, which, if they are left in their place of origin, enrich the soil and, in this manner, protect the roots as natural means of soil erosion control (see Section 4.1.3).

Another threat to biodiversity is expected to result from the field of biotechnology. Concerns already arose due to long-term – generally unpredictable – consequences of the uncontrolled introduction and spread of genetically modified organisms (GMOs) into soils, organisms, and crop populations (SRU (2007), p. 52, UNEP (2007), p. 36). At present GMOs with respect to bioenergy crops are still in their early stage of development and, yet, only applied on test areas (SRU (2007), p. 52). Regardless of the fact, that genetic improvement of feedstocks is assessed to be necessary in order to improve both the economic as well as the energy efficiency, the pros and cons accompanied by the potential spread of GMOs demand further investigation (DUFEY (2006), p. 45).

By contrast, bioenergy crop production can also create an environment that is more biodiverse and similar to a natural habitat than other agricultural options, thus, biomass, respectively biodiversity could be enriched (KARTHA (2006), p. 2). This is most likely in case of perennial crops like trees and grasses that require lower inputs and can be cultivated on degraded land, thereby promoting land restoration (DUFEY (2006), p. 44).

4.2 Social Impacts of Biomass Production

4.2.1 Land Availability

An intensification of agricultural land use as well as further pressure on land expansion is already expected due to a growing demand for food and fodder, and wood as a consequence of global population growth, economic development, changes in diet and increasing opportunities to export food and fodder (FRITSCHE et al. (2006), p. 11, SRU (2007), p. 60). As a consequence of intensified agricultural production the area of available land is further reduced due to ongoing degradation[36] and salinisation of currently cultivated land, limits of irrigation and continuing desertification (FRITSCHE et al. (2006), p. 11).

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[36] At present, degraded land worldwide is assessed to be about 1 billion hectares which represents a minimum bioenergy potential of around 100 EJ per year (FRITSCHE et al. (2006), p. 11).

Due to the fact, that both require identical production factors, the potential future increases in bioenergy crops is competitive with the production of crops for food and feed and therefore, putting pressure on increased land use, too (SRU (2007), p. 60). As energy markets are greater in value terms than agricultural markets, prices for agricultural commodities which can also function as energy crops are rising (SCHMIDHUBER (2007), p. 19, NYBERG et al. (2007), p. 3). Hence, there is a clear correlation between the price development of energy crops on one hand and food as well as feed prices, respectively, on the other hand. According to SCHMIDHUBER ((2007), p. 49) the recent trends will lead to a reversal of the decline in real agricultural prices continuing over the last 40 years including prices for land and other production factors. Accordingly, a shift from high to low quality land for food production purposes is likely to occur, as it is less profitable than biomass production.

4.2.2 Food Supply and Food Security[37]

At present the global food production is sufficient to supply the entire global population.[38] Hence, the fact that malnutrition and nutritional deficiency is still existent is not a problem of production but rather a problem of allocation – predominantly due to missing purchasing power but also for several other reasons[39] (SRU (2007), p. 61, DUFEY (2006), p. 49, CASSMANN et al. (2007), p. 20). In this context a major concern linked to growth in bioenergy production is that it could exacerbate the situation of food security, especially in developing countries, since a greater demand for biofuels will lead to a drawback of land from other purposes like food production, which could in fact lead to food shortages and higher food prices (DUFEY (2006), p. 48, see also Section 4.2.1). On the other hand, biomass production can also contribute to alleviate poverty and improve food affordability by creating jobs and incomes (FRITSCHE et al. (2006), p. 14).[40]

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[37] The FAO defines food security as a „situation that exits when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietay needs and food preferences for an active and healthy life“ (FAO (2002))

[38] Nevertheless, 854 million people in this world suffer from hunger, and although the proportion of undernourished has declined over recent years, absolute figures have remained constant (GBEP (2007), p. 4).

[39] Food security is indicated by a plethora of factors, such as the percentage of people who are chronically undernourished, adult literacy (particularly female), the proportion of household income spent on food, population growth, per capita GDP growth, agriculture‘s contribution to GDP, health expenditure as a percentage of GDP, the proportion of adults infected with HIV, the number of food emergencies, the UNDP Human Development Index, the degree of export dependence, domestic food production (food availability), purchasing power (food access), access to water and sanitation facilities (food utilization) (FRITSCHE et al. (2006), p. 14).

[40] In Brazil the sugar cane-ethanol industry accounts for 4.2 million jobs. In Indonesia the palm oil industry is expected to create 2.5 million jobs over the next three years (CASSMANN et al. (2007), p. 20).

The potential impact of the continuously increasing bioenergy demand on food security is highly context specific and complex. It is obvious, that net buyers of food will be hit negatively by a persisting bioenergy boom. This would – most likely – affect small farmers in marginal areas, urban and land-less rural and urban poor as their major part of total household expenditures is spent for basic commodities such as maize and sugar (SRU (2007), p. 61). On a national level this is especially problematic to most of the LDCs as they are net buyers of both energy and food (BRAUN et al. (2007a), p. 40, SCHMIDHUBER (2007), p. 41).[41]

4.2.3 Land-Use Conflicts

In many developing countries rural dwellers have neither a formal ownership over the cultivated land nor formal rights to water access. As an increasing production of energy crops, especially large-scale feedstock production, probably goes along with an expansion of the agricultural land, potentially evoking conflicts over land rights and 'landlessness' issues in many developing countries. As a consequence, rural population could be forced to migrate, losing their access to key forest resources and ecosystem services (DUFEY (2006), p. 49). Also the use of marginal and degraded lands – which some countries, including India[42], have singled out for bioenergy development – for the production of biomass can even further intensify problems for poor households as in many cases this land provides important subsistence functions to the most vulnerable part of the population (GBEP (2007), p. 3).

4.2.4 Other Impacts

According to the general set-up, biomass cultivation can have negative impacts on working conditions, such as the disregard of safety precautions, the exploitation of workers by very low wages, forced overtime, child and forced labour[43] (quasi-slavery). Workers` health can be affected especially by the (incautious) use of pesticides or from air pollution due to the burning of fields. Environmental damage or contamination going along with the cultivation of biomass can also have indirect impacts on the local population. For example, the quality of

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[41] At present, compliance with the standard of food security is extremely difficult to measure, since there is no direct link between food (in) security and bioenergy, and quantified expressions of food-security levels only seem possible on a countrywide scale, where factors such as employment, income distribution, welfare expenditure, legal rights (especially of land ownership), and education are far more important than the impact of local bioenergy crop production (FRITSCHE et al. (2006), p. 14)

[42] The Indian government has planed that by 2012 some 14 million hectares of the energy crop Jatropha will be cultivated on 'wasteland' (NO AUTHOR (2007), p. 3).

[43] For example in remote areas in Brazil child and forced labour is a serious issue in the agricultural sector. "For example, various newspapers reported in mid 2007 a case of more than 1000 "slave workers" who were forced to live and work in an agricultural production unit in the Amazon area."(SCHMITZ (2007), p. 1475)

drinking water can decrease due to water pollution whilst soil erosion can reduce the area for future cultivation (FRITSCHE et al. (2006), pp. 20 f., SRU (2007), pp. 61 f.).

4.3 Economic Impacts

The economic viability of biofuels predominantly depends on the economic costs of its production as well as on the market prices of biofuels, indirectly dependant on the world market prices of fossil fuels. Moreover, the existence of a suitable infrastructure for transport and distribution of both the feedstock and the biofuel is of importance, especially in most developing countries where a lack of infrastructure prevails and therefore, puts a constraint on the development of the biofuels sector (DUFEY et al. (2007), p. 6).

Production costs can vary greatly according to the type of biofuel, feedstock, the country of provenance and the technology used (DUFEY et al. (2007), p. 6). Thereby, feedstock costs are responsible for the lion's share of production costs of biofuels (50–70 % for ethanol; 70-80 % for biodiesel). Hence, a change in feedstock costs can have a huge effect on overall costs (BRAUN (2007), p. 19). Additionally, costs for labour and other inputs, environmental compliance costs during the production process, costs of conversion (including investment needs) have to be considered. On the revenue side income is generated by the respective biofuel itself as well as by co-products. In general, it can be said, that small-scale operations cause higher costs than large-scale operations (DUFEY et al. (2007), p. 6).

Alongside production cost global prices of crude oil determine the profitability of biofuels. Estimates show that according to production costs sugar cane produced in Brazil's south centre region is already coming competitive when the oil price reaches US$ 28 per barrel while Brazil's average lies at US$ 35 per barrel.[44] By contrast the BtL production in Europe is not competitive unless the oil price reaches a barrel price of almost US$ 100 (SCHMIDHUBER (2007), pp. 20 f.). Figure 6 comprises different feedstocks, farming systems and fuels and

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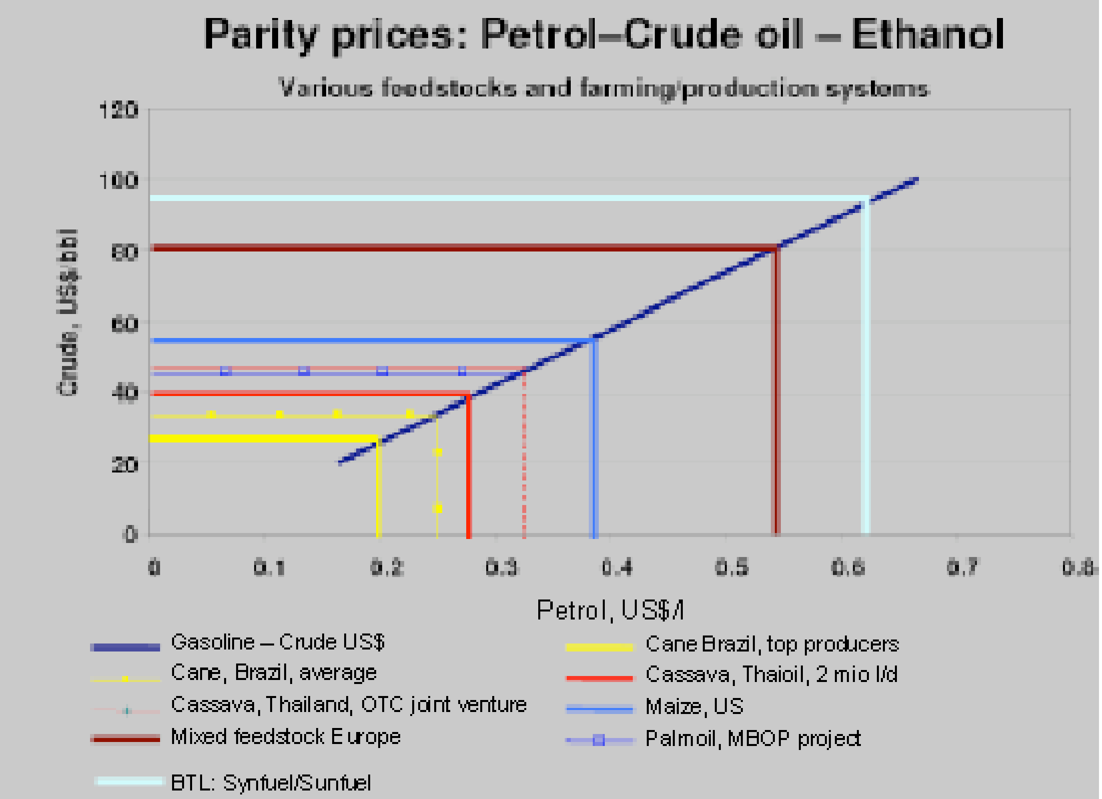
[44] At present Brazil is the most cost-efficient producing country for bioethanol. The production cost for one litre biofuel from sugar cane is around US$ 0.25 (DUFEY et al. (2007a), p. 19). Countries as Thailand, Pakistan, Swaziland and Zimbabwe face production costs similar to Brazil's (DUFEY (2006), p. 38). The US, China and Australia have production costs differing roughly between US$ 0.40-0.50 whereas within the EU production costs are highest, varying from US$ 0.51 to 0.80 per litre of biofuel. Regarding the production costs of biodiesel there is no dominant leader like Brazil for bioethanol. The most cost efficient producing countries are within the EU, the US and India sharing a maximum cost-efficiency of US$ 0.40 per litre. Within these countries cost-efficiency strongly vary and can reach up to US$ 0.80 per litre of biofuel as it is the case within the EU (DUFEY et al. (2007a), p. 19). APPENDIX I (Table III) gives an overview of production costs for bioethanol and biodiesel for selected countries.

their particular break-even points with respect to compete with the crude oil price per barrel for selected countries.

Figure 6: Parity Prices for various First Generation Feedstocks



Source: SCHMIDHUBER (2007), p. 22.

Due to the fact, that the biofuel sector is usually not commercially viable without assistance[45] – at least in the early stage of sector development – current biofuel growth has mainly been driven by the respective policy incentives so far, thus, exerting pressure on government revenues (GBEP (2007)).

Due to the instantaneously high global petrol price – which currently is more than US$ 100 per barrel – biofuel production has temporarily become economically feasible in some countries without sustained governmental support. The continuation of this price trend would c. p. expand and improve the chance for other biofuels programs, too (DUFEY et al. (2007), p. 6). Nevertheless, it is realistic to assume that a more intense competition from alternative fuels traded in large quantities on a global scale will cause a decreasing oil price in the medium to

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[45] Currently just a few modern bioenergy technologies are viable at market prices. These include brasilian sugar-based ethanol and wood-based heating in Northern Europe, and importantly industrial applications based on residues from production processes, for instance in sugar factories and timber mills (GBEP (2007)).

long term (DUFEY (2006), p. 38). Therefore, governmental support is assumed to remain a prerequisite to biofuels sector development.

5 Assessing the Sustainable Jatropha Production in San Martin, Peru

5.1 Country information of Peru

As the previous chapter has shown, numerous important problems and conflicts could arise from an increased bioenergy supply affecting the environment, society, and the economy (FRITSCHE et al. (2006), p. 6). The extent to which the aforementioned problems might occur, respectively, whether they outweigh the potential benefits, depends on the respective frame conditions (political, judicial, (macro-) economic). Therefore, in the following – after a general introduction of Peru with special focus on the agriculture as well as the energy sector is given, basic information of the Peruvian biofuel sector is provided as the basis for further analysis.

5.1.1 Geography and Climate

Peru is situated in Western South America at the South Pacific Ocean. Its bordering countries are Ecuador and Columbia to the North, Brazil in the West, Bolivia in the Southwest and Chile in the South. Peru has a total area of 1,285,220 km^2. This almost equals the size of France, Germany and Italy together. 5,220 km^2 or 0.41 % of the country's surface is covered with water (WORLD FACT BOOK (2008)).

Peru has the most diverse climate in the world including 28 out of 32 possible climate zones Although reality is by far more complex, in general the Peruvian climate zones can be distinguished between the coast, the Andes and the Amazonian rainforest.

The climate on the coast is generally subtropical and receives only little rainfall. It ranges from warm-semiarid in the north to cool-arid on the south coast. The average temperature is around 18 to 20 °C (FAO (2008)). The central and southern coastal climate varies by season. In winter – from April to October – the temperature ranges from 8 at night to 23 °C during the day, and in summer – from November to March – between 18 to 30 °C. Rainfall in summer rarely exceeds 10 mm while the rainy season is from May to October with a precipitation between 10 and 150 mm.

The north coast is characterized by hot humid and sunny conditions almost throughout the year. Lowest temperatures in winter range from 14 to 18 °C at night and 22 to 29 °C during the day. In summer temperatures vary between 20 and 23 at night and 28 and 38 °C during the day. While in summer rainfall is around 200 mm, in winter there is no rainfall (FAO (2008), PEP (2008)).

In the Andes two seasons occur, a dry season from April to October and a rainy season from November to March. The first is characterised by sunny days, cold nights and mornings and is very dry with almost no rainfall while the latter predominantly features frequent rain showers with generally more than 1000 mm. During the rainy season snowfall occurs frequently above 5000 m and occasionally above 3800 m. According to the altitude, the temperature ranges from an annual average of 18 °C in the lower situated valleys to an annual average below 0 °C in the highest altitudes (PEP (2008)).

The Peruvian rainforest is characterized by a temperate subtropical climate and a high humidity throughout the year. The rainy season starts in November and ends in March, but also during the dry season rain showers can occur occasionally. Total rainfall is around 3000 mm per year. The dry season lasts from April to October – with temperatures most of the times above 35 °C. In May and August cold snaps occur occasionally in the southern part of the rainforest leading to temperatures between 8 and 12 °C due to cold fronts coming from the South (FAO (2008), PEP (2008)).

5.1.2 Sociological Context

Peru's population is estimated to be around 28.5 million in 2007 (WORLD FACT BOOK (2008)). The population growth rate is about 1.6 % (CARE (2008)). The linguistic and cultural structure is very diverse. Besides of two official languages – Spanish and Quechua – Aymara and a number of minority Amazonian languages exist (BBC (2008)). The ethnical mixture is predominantly determined by two groups. The Amerindians – indigenous people of the Americas – with a total share of 45 % and the so-called Mestizos – mixed indigenous and white people – with a share of 37 %. White people account for 15 % while black, Japanese, Chinese and others account for 3 % (WORLD FACT BOOK (2008)).[46]

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[46] Table 9 gives an overview of selected key factors of the socio-economic situation of Peru.

Table 9: Selected Key Facts of the Socio-economic Situation in Peru

Indicators			
Population (in million) Annual Population Growth rate (in %)	28.67 1.61 %	**Life expectancy at birth in years** (2007 est.) Female Male	70.14 72.04 68.33
Religion (2003 est.) Roman Catholic Seventh Day Adventist Other Christian Other Unspecified or none	81 % 1.4 % 0.7 % 0.6 % 16.3 %	**Population undernourished** (% of total population (2004)	12 %[1] 25 %[2]
Literacy - age 15 and over; read & write (2004 est.) Female Male	87.7 % 82.1 % 93.5 %	**Population using improved water sources** (2004 est.)	83 %
Average Structure of Age (2007 est.) 0-14 years 15-64 years 65 years and over	30.3 % 64.2 % 5.4 %	**HIV/AIDS** – adult prevalence rate (2003 est.)	0.5 %
Urban Population	73 %	**Population below 1 / 2 US$/day** (1990-2005)	10.5 % & 30.6 %
Human Development Index rating (2007/08)	87 (out of 177)		

[1] Source: FAO (2008).
[2] Source: BECKER (2007).

Source: CARE (2008), WORLD FACT BOOK (2008), UNDP (2008), FAO (2007).

5.1.3 Political Context

According to the constitution, the Republic of Peru is a unitary and decentralised state. The government is representative, decentralised and based on the principle of separation of powers. The president is eligible only for a single five-year term. At the moment Alan García Perez is occupying the presidential office. He was elected in 2006 and his term ends in July 2011 (PEP (2008)).

Figure 7: Administrative Structure of Peru

Source: NO AUTHOR (2008b).

The country is divided into 24 departments (see Figure 7), further subdivided into 195 provinces and 1,828 districts, respectively, with each department having its own capital. Since the regionalisation of the country in 2002 each of the departments is a self-governing unit with agencies elected directly including political, economic, and administrative autonomy within the scope of the department. Peru belongs to the ten-member Andean Community of Nations (CAN), which was founded in 1969. The objective of the CAN is the achievement of economic, political and social integration among the member countries (WIKIPEDIA (2008)). Furthermore, Peru participates in several international organizations such as MERCOSUR, UN or WTO just to mention a few (WORLD FACT BOOK (2008)).

5.1.4 Economic Context

Until the early 1990`s the Peruvian economy mainly featured reforms made by the government of Juan Velasco Alvarado from 1968 to 1975. These included price controls, protectionism, restrictions of foreign direct investment, and the nationalisation of most companies. The reforms failed and its objectives - income redistribution and the end of economic dependence on developed nations - were not achieved. In the early 1990's the government of Alberto Fujimori broke up significantly with the old economic policy introducing liberalisation covering all afore mentioned aspects. Except for some years following the Asian financial crisis in 1997, the reforms led to a continuous economic growth from 1993 onwards (WIKIPEDIA (2008)). Between 2002 and 2006 the mean annual growth rate was more than 4 % and reached 7.5 % in 2007 (WORLD FACT BOOK (2008)). The growth is mainly driven by traditional export sectors such as fisheries and mining whose production levels are growing constantly due to continuously rising world market prices for metals and minerals. The fiscal policy turned much more prudent and transparent, which has led to a more stable exchange rate as well as a low inflation. Despite Peru's macroeconomic progress, problems like underemployment, poverty and social end economic inequality remained persistently high for large parts of the population (EU (2005), WORLD FACT BOOK (2008), FOREIGN AND COMMON WEALTH OFFICE (2008)).[47]

Table 10: Overview of Key Figures of the Economic Situation in Peru

GDP (in billion US dollars in 2007)	84.54
GDP – average annual growth rate (in % from 1990-2005 / 2006 / 2007)	2.2 / 6.4 / 7.5
GDP per capita (in 2005 in US $)	2838
Inflation rate 2006 (consumer prices; in %)	1.14
GDP by sector (in %) in 2007	
Agriculture	8.4
Industry	25.6
Services	66
Labour force in 2007 – (in million) By occupation per sector (in %)	8.9
Agriculture	31.2
Industry	18.9
Services	49.9
Employment	
Unemployment rate (in %)	8.9
Underemployment rate (in %)[48]	51.4
Budget in billion US$ in 2007	
Revenues	30.35
Expenditures	29.8

Sources: IndexMundi (2008), EMERY (2008), INEI (2007), INEI (2008), WORLD FACT BOOK (2008), UNDP (2008), RODRIGUEZ (2005)).

With regard to international trade, Peru has a positive balance. In 2007 exports accounted for 27.1 billion, while imports accounted for US$ 18.8 billion, leading to a trade surplus of US$ 9.4 billion. Major trading partners are the US, China and other Latin American countries. The

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[47] Table 10 gives an overview about key figures of the economic situation in Peru.

[48] The underemployment rate indicates the part of the population having a job but working less than 35 hours per week or working 35 hours or more a week and earning less than a minimum wage to secure one`s livelihood. The average underemployment rate of 51.1 % is composed of 45.1 % in urban and 62.8 % in rural areas (RODRIGUEZ (2005)).

Peruvian export structure is heavily depending on minerals and metals and therefore, the economy is subject to fluctuations in world prices (WORLD FACT BOOK (2008)).

5.1.5 The Agricultural Sector

Although the participation of the agricultural sector to Peru's GDP (8.4 % in 2007; see Table 10) is relatively low compared to the service and industry sector, agriculture is of great socio-economic relevance. It employs 2.8 million people or 31.2 % of Peru's economically active population, but altogether 31.6 % of the population (8.1 million people) are living from agriculture (MINAG (2008)).

The total area of Peru is 128.5 million ha of which about 2.9 % is arable land. Of this 3.7 million ha of arable land 15.8 % is dedicated to permanent crops. Around 28 % of this area is irrigated. Pasture land has a share of 13 % and degraded land accounts for roughly 14 % of the total area. Absolute figures are given in Table 11. Major agricultural products are sugar crops, fruits & vegetables, roots & tubers and cereals. Table 12 gives an overview about agricultural production according to the product group.

Table 11: Land Data of Peru

Land Data	In 1000ha
Total Land area	128 500
Arable land with permanent crops	585
Arable land used otherwise	3 115
Pasture Land	16 900
Total land area irrigated	1 036
Total degraded land	17 900

Sources: FAO (2005), FAO (2007).

Table 12: Structure of Agricultural Production in 2004

Product Groups	Production in 1000t
Sugar Crops	9 680
Fruits & Vegetables	5 720
Roots & Tubers	4 400
Cereals	3 389
Milk	1 285
Meat	958
Pulses	185
Oilseeds (oil equiv.)	82
Other	445
Total	26 144

Sources: FAO (2007).

According to the FAO (2007), cereals, fruits & vegetables, roots & tubers, milk and sugar account for the largest share of consumed foodstuff. The main food crops are sugar, rice, potatoes, wheat, and maize. Among the tree crops coffee remains by far the most important one. Poultry is the most consumed meat in Peru followed by Pig and Bovine Meat (FAO (2007).

In 2006 exports of agricultural products accounted for only 2.4 % of the total export value or – in monetary terms – US$ 573 million compared to a total of 23.8 billion US$. Main agricultural export goods in 2006 in terms of value share were coffee (89.9 %) followed by sugar refined (7.5 %) and Cotton (1.2 %). Agricultural imports accounted for 3.1 % (468 million US$) of the total value of national imports (14.9 billion US$). Main agricultural imports were wheat, soybean and maize (BCRP (2006), pp. 61-66).

5.1.6 The Energy Sector

The total energy consumption of Peru in 2006 was 498,121 TJ compared to 477,173 TJ in 2005, corresponding to a growth of about 4.4 %, whereby secondary energy accounted for the largest share of 77.6 % and primary energy for 22.4 %. Within secondary energy consumption diesel oil with 33 % was the greatest part, followed by electricity with 22.7 %. In case of primary energy the use of wood was by far the largest (66.9 %), followed by cow pats & Yareta.[49] The consumption structure corresponding to energy sources is shown in Figure 8

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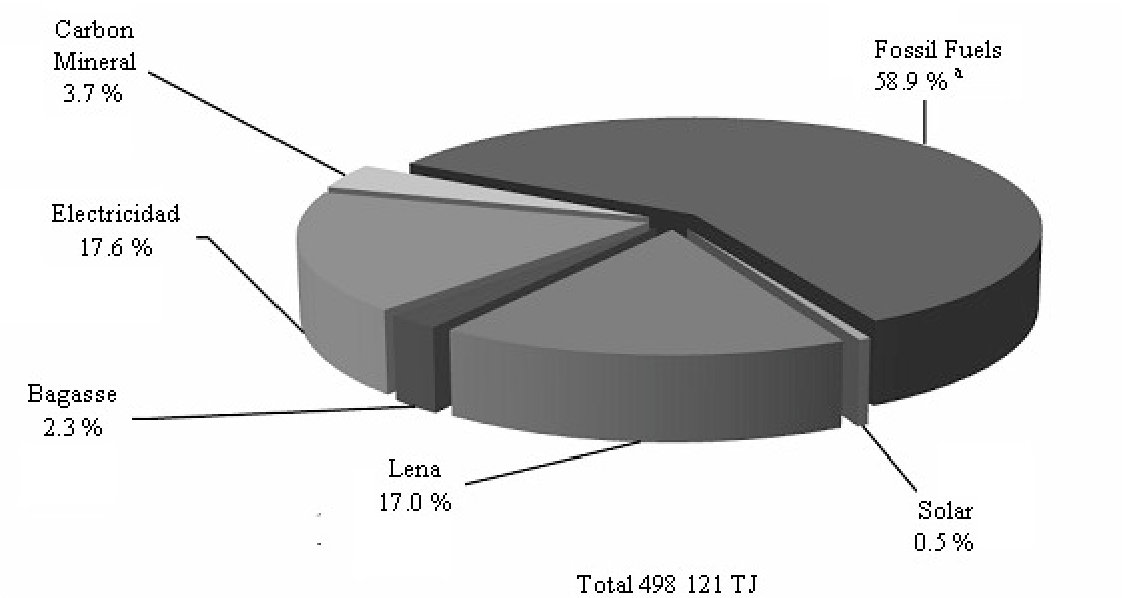
[49] Yareta (*Azorella compacta*, also known as *Azorella yareta*) is a tiny flowering plant in the family Apiaceae native to South America, occurring in the Puna grasslands of the Andes in Peru at between 3200 and 4500 metres altitude (WIKIPEDIA, 2008).

Figure 8: Total Energy Consumption by Sources in 2006[50]



[a] The contribution of diesel oil is around 127,903 TJ or 25.7 % to total final energy consumption

Source: MEM (2006), p. 18.

In 2006 the trade balance for primary energy was negative, while the one for secondary energy was positive. In that period Peru realised net imports of crude oil in the amount of 163,515 TJ (213,930 imported – 50,414 exported) and net carbon imports of 21,237 TJ (no exports). Net exports of secondary energy carriers, in this case only fossil fuel derivatives, accounted for 44,775 TJ (95,243 exported – 50,468 imported), whereby gasoline accounts for 38.3 % of gross exports (MEM (2006), pp. 8-18). While Peru is a net exporter of gasoline, it is a net importer of diesel. This deficient status of the diesel production causes first a high dependence on imports and second continuously growing expenses due to constantly increasing oil prices (ARÉVALO et al. (2007), pp. 9 f.).[51]

Despite total energy consumption in Peru has increased significantly within recent years – from 373,265 TJ in 1990 to some 498,121 TJ in 2006 – the repartition among the population remains uneven. Only a share of 79 % of the total population has access to electricity while in rural areas this figure is only about 30 %. More than six million people do still not have any

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[50] In Appendix I (Table IV) a more detailed overview about the final energy consumption according to each single source is given.

[51] In 2006, the average daily demand for fossil fuels in Peru was about 168 million barrels per day of which around 60 million barrels per day corresponded only to diesel oil consumption. Only 25 % of the entire diesel oil demand was made of national crude oil whereas the major share of 48 % was produced with imported crude oil and another 27 % was directly imported as diesel oil. In other words, three quarters of diesel which is consumed in Peru is imported (ARÉVALO et al. (2007), pp. 9 f.).

access to electricity (MEM (2006), p.18, MEM (2008)). Although in 2006 the use of fire wood as an energy source represents only 15 % of the total energy consumption, only in the private sector energy from fire wood accounted for more than 57 % of the total energy consumed. That means that more than half of the energy consumed by households and companies is based on traditional biomass. Besides problems with respect to deforestation, this causes serious health problems among the population, such as respiratory diseases (ARÉVALO et al. (2007), p. 5, MEM (2006), p. 18).

5.2 Biofuels in Peru

5.2.1 Introduction

In recent years biofuels have gained increasing attention in Peru, and (some first) important steps – such as the establishment of a regulatory framework and mandated blends of biofuels – were made to promote the domestic biofuels industry. Furthermore, investments and the creation of R&D incentives are already planned in order to supplement these first measures. The motivation behind is the wish of the Peruvian government to modify the actual energy matrix in order to decrease the strong reliance on non-renewable energy resources – which account for around 70 % of the current energy supply – by developing sources of renewable primary energy which are abundantly available within the country (MEM (2007), p. 33). Thereby, the domestic production of biofuels shall contribute to a reduction of fossil fuel imports - such as crude oil in first and diesel oil in second place (see Section 5.1.6) – accompanied by currency exports in order to enhance the national energy security (CASTRO et al. (2008), p. 141). Additionally, biofuels are regarded as an instrument to reduce pollution, to foster rural development, to create jobs across the country, and to combat the production of illegal drugs in Peru (ROTHKOPF (2007), p. 99).

5.2.2 Government Policies

Peru's legal framework for the promotion of its biofuel sector is based on two instruments, first, the Biofuel Market Law No. 28054 (Ley N° 28054 – "Ley de Promoción del Mercado de Biocombustibles) – also called PMB Law –passed in 2003 (República del Perú (2003)) and second, the Surpreme Decree N° 013-2005-EM (República del Perú (2005)) enacted in 2005.

These two laws constitute national production and commercialisation targets regarding the blends of biodiesel to diesel as well as ethanol to gasoline, i.e.

- By the 1st of January 2009 respectively 2011 it will be mandatory to sell blends of biodiesel with conventional diesel of 2 % and 5 % in the latter case. These blends will be denominated Diesel B2 and Diesel B5.

- By the 1st of January 2010 it will be mandatory to sell blends of gasoline with ethanol of 7.8 %. This blend will be denominated "Gasohol".

Both, the PMB Law as well as the Surpreme Decree insist that all projects linked to the production of biofuels have to comply with standards given by the National Environment Council in order to guarantee a sustainable development. These include, for example, the improvement of the economics of farmers associated to a biofuel chain as well as the prioritized use of land that is already deforested, degraded or abandoned (ROTHKOPF (2007), p. 100, ARÉVALO et al. (2007), p. 4).

Currently there are no tax incentives or price subsidies. Concerns already arose that if state interventions will not take place, the ethanol as well as the biodiesel industry will not be competitive to regular fuels (ROTHKOPF (2007), p. 100). At the moment there is a debate about introducing a tax relief for biofuels but not with any ultimate outcome so far (AHK (2007), p. 4).

On the international level Peru has two cooperations with Brazil concerning biofuels. One is a programme on biotechnology and biofuels prolonged in 2006 between the National Council of Science, Technology and Technological Innovation (CONCYTEC) of Peru and the Agricultural Research Corporation of Brazil. Another agreement signed in 2006 between the two governments relates exclusively to the joint development of alternative crops for biofuels. Furthermore, Peru signed a Free Trade Agreement (FTA) with the US allowing the export of biofuels. As Peru is also a member of MERCOSUR – a common interior market in South and Central America – concerns exists that lower-cost biofuels from Brazil could enter the market before Peru's biofuels industry can reach cost-efficiency (ROTHKOPF (2007), p. 100).

5.2.3 National Demand for Biofuels

The demand for biofuels in Peru is relatively low. In 2003 the demand for bioethanol was around 30 million litres and was mainly due to the industry, the medical sector and private consumption (ROTHKOPF (2007), p. 101, CASTRO et al. (2008), p. 78). Concerning biodiesel there is no data available recording any real current demand.

Due to the legal frame set by the PMB Law (see Section 5.2.2) the current demand situation for bioethanol and biodiesel will change significantly within coming years as mandated blends to diesel and gasoline are required from 2009 onwards. Table 13 shows the projected national demand for fuels from 2009 to 2016 measured in million barrels per day (mbpd).

Table 13: Projected National Demand for Fuels from 2009 – 2016

Fuels (mbpd)	**Years**							
	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Diesel	62.80	64.10	65.50	67.00	68.50	70.10	71.80	73.60
Gasoline[52]	18.00	17.40	16.80	16.20	15.60	15.10	14.60	14.10

Source: own illustration, following ARÉVALO et al. (2007), p. 11.

5.2.3.1 Projected National Demand for Bioethanol

In 2006 the total national demand for gasoline was about 306 million gallons which corresponded to 20 mbpd (ARÉVALO et al. (2007), p. 11, MEM (2007), p. 36). By 2010 the national gasoline demand is expected to decrease to some 289.74 million gallons. Applying the required blend of 7.8 % the demand for bioethanol will be around 22.6 million gallons or 85.4 million litres (ARÉVALO et al. (2007), p. 11).[53]

In case only sugar cane is used to satisfy the bioethanol demand in 2010 an agricultural area of 13,000 hectares would be needed according to calculations done by the ARÉVALO et al. (2007) – presuming an average yield of 93.8 tons per hectare and 70 litres of bioethanol per ton across the country (ARÉVALO et al. (2007), p.11, 13). Table 14 shows the projected national demand for bioethanol according to the expected national gasoline demand in million gallons from 2010 to 2013.

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[52] The projection already considers the substitution effect of an extended use of natural gas (ARÉVALO et al. (2007), p. 11).

[53] Note: 1 gallone corresponds to 3.78 litres (Wikipedia (2008), http://de.wikipedia.org/wiki/Gallone.)

Table 14: Projected National Demand for Bioethanol from 2010 to 2013

Fuels (in million gallons)	Years			
	2010	**2011**	**2012**	**2013**
Gasoline	289.74	285.90	282.05	278.21
Bioethanol	22.60	22.30	22.00	21.70

Source: own illustration, following ARÉVALO et al. (2007), p. 11.

5.2.3.2 Projected National Demand for Biodiesel

In 2006 the total demand for conventional diesel was 905 million gallons which is equal to some 60 mbpd. By 2009 the national demand for diesel is expected to grow to some 1,060 million gallons (ARÉVALO et al. (2007), p.11, MEM (2007), p. 36). With the beginning of the mandatory blending of Diesel B2 in 2009 the demand for biodiesel will be around 0.52 million barrels or around 21.2 million gallons. In 2011 – when a blending of 5 % is obligatory (Diesel B5) – the biodiesel demand is expected to increase to some 1.35 million barrels or 56.9 million gallons (CASTRO et al. (2008), p. 104). Table 15 shows the projected national demand of biodiesel according from 2009 to 2013.

Table 15: Projected National Demand for Biodiesel from 2009 to 2013

Fuels (in million gallons)	Years				
	2009	**2010**	**2011**	**2012**	**2013**
Diesel	1,060.00	1,090.00	1,138.00	1,168.00	1,212.00
Biodiesel (2 %)	21.20	21.80	-	-	-
Biodiesel (5 %)	-	-	56.90	58.40	60.60

Source: own illustration, following ARÉVALO et al. (2007), p. 11.

Without considering the demand of vegetable oils for human consumption, the demand for Diesel B2 expected by 2009 would require around 17,000 hectares of palm oil or 84,000 hectares of rape-seed plantations, and around 45,000 hectares of palm oil or 226,000 hectares of rape-seed plantations for the Diesel B5 demand by 2011 (CASTRO et al. (2008), p. 104).[54]

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[54] The calculations are based on the assumptions of an average yield of around 4,276 litres/ha of palm oil and 2,550 litres/ha of rape-seed oil (CASTRO et al (2008), p. 104, ARÉVALO et al. (2007), p. 11).

5.2.4 National Production of Biofuels

Peru's agriculture is very favourable for the production of biofuels as it has a huge variety of crops to produce both, ethanol and biodiesel[55] as well as some very good preconditions with respect to climate and soil (AHK (2007), p. 4). Among the crops to produce ethanol sugar cane is very competitive as its average yield per hectare is the highest in the world with around 130 tons per hectare (CASTRO et al. (2008), p. 79).[56] The average yield of 4,700 litres of oil per hectare of palm oil is also very high. Furthermore, very promising crops include sorghum and potatoes to produce ethanol and jatropha, castor oil plant and rape-seed to produce biodiesel (PROINVERSION (2008), p. 2), CASTRO et al. (2008), p. 104).

The produce of ethanol is quite low. Most recent figures available state that in 2003 80 % of the sugar cane production was dedicated to sugar production, while only 30.4 million litres of ethanol were produced. Regardless of the fact, that Peru is producing large quantities of palm oil – around 48,000 tons in 2005 – which can be used for biodiesel there is no significant biodiesel production reported at all (ROTHKOPF (2007), p. 101, CASTRO et al. (2008), p. 88).

5.2.5 Investments in Biofuels

According to investment projects for ethanol production, that are already in process[57], the area cultivated within the next years will be around 220,000 hectares and is almost exclusively dedicated to sugar cane production.[58] The corresponding yield is expected to potentially reach some 1,098 million tons of sugar cane per year, which would – assuming an average yield around 90 litres per ton of sugar cane – approximately equal some 98.8 million litres of ethanol. Of the whole area dedicated to announced ethanol production, 164,000 hectares will be newly cultivated while the remaining 56,000 hectares are already in use for sugar cane production (CASTRO et al. (2008), pp. 73-79).

Available data with respect to investment projects for biodiesel production within coming years is on the one hand scarce and on the other hand greatly varying. The figures published between 2007 and 2008 based on investment projects already being performed or announced

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[55] Namely, these are – for the production of ethanol – sugar cane, maize, cassava, rice, potatoes, and sweet sorghum as well as – for the production of biodiesel – jatropha, caster-oil plant, palm oil, rape-seed, coconut, soy, cotton, and sunflower (ARÉVALO et al. (2007), p. 7).

[56] For comparison: Brazil has a yield of 73 tons per hectare (ROTHKOPF (2007), p. 101).

[57] There are already a growing number of foreign investments including international cooperations as well as foreign direct investments (Castro et al. (2008), p. 73).

[58] Only a small fraction of about 300 hectares is announced to be dedicated to the cultivation of sorghum. See Appendix I (Table V) for an overview of the respective investment projects.

estimate that the production level of biodiesel will range between 104 and 670 million litres corresponding to 27.5 respectively 177.2 million gallons per year with production based exclusively on palm oil and rape-seed (CASTRO et al. (2007), p. 82., CASTRO et al. (2008), p. 103, PROINVERSION (2008), pp. 2 f.). Table 16 gives an overview of the publications and their varying estimations concerning biodiesel production within coming years.

Table 16: Expected Biodiesel Production within coming Years based on Investment Projects in Construction or Announced[59]

Author	Publication Date	Biodiesel Production (mill. Gallons)	Area demanded (1000 ha)	
			Palm Oil[60]	Rape-Seed[61]
Castro et al.	2007	27.5	22.1	109.47
Castro et al.	2008	92.5 – 177.2	74.7 - 142.6	368.4 – 705.3
PROINVERSION	2008	29.8	24	-

Source: own illustration, following Castro et al. (2007), p. 82, Castro et al. (2008), pp. 104 f., PROINVERSION (2008), pp. 2 f.

If all investment projects currently in process will be successfully finished and all announced investments will be realized, the production of both, ethanol and biodiesel could increase significantly within coming years (see Table 16 and Appendix I (Table V)).

Nevertheless, it is very important to notice, that at the moment it does not look as if the mandatory blends of biofuels to fossil fuels that are required by the beginning of 2009 can be fulfilled. This assumption seems to be well reasonable, since on the one hand the actual production of ethanol and biodiesel is far too low compared to the target by 2009 onwards and on the other hand many projects are either in process of planning and possibly searching for financial resources, or may not be in place at all (CASTRO et al. (2008), pp. 77, 103).

Additionally, there are several – mainly small-scale – R&D projects, which are quantitatively not worth mentioning, but in most cases offer the opportunity to take further steps in the development of the Peruvian bioenergy sector, such as the one implemented by the DED in Leoncio Prado, San Martín, which is described below (see Section 5.4.1).[62]

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[59] In all three publications mentioned there is no exact date available about when these expected production capacities for biodiesel will be in place.

[60] For palm oil a yield of 4,700 l/ha corresponding to 1243.3 gallons/ha of biodiesel was applied.

[61] For rape-seed a yield of 950 l/ha corresponding to 251.3 gallons/ha of biodiesel was applied.

[62] A comprehensive overview of currently realised private and public R&D projects can be looked up in ARÉVALO et al. (2007), pp. 27-34.

5.3 The Sustainable Cultivation of Jatropha

Regardless of the very promising characteristics attributed to jatropha, only little systematic research has been done on it so far, and most of the current projects are still in their early stage of development (OUWENS et al. (2007), p. 1). Hence many uncertainties and knowledge gaps still exist concerning the question whether and how jatropha can be cultivated and used for biofuel production in a sustainable way (ACHTEN et al. (2007), p. 289). In order to answer this question, three dimensions are to be taken into account, the ecological, the social, and the economical one. Due to the existing uncertainties and measurement problems regarding the former two criteria, in the following they are discussed mainly qualitatively, after a brief introduction of jatropha as a bioenergy crop is given. In Section 5.4 the effort is undertaken to assess the economic value by means of an empirical mathematical model using data currently being generated by the DED.

5.3.1 Jatropha - Characteristics and Potential

Jatropha Curcas L. (Piñon) – in the following alternatively denoted as *jatropha* - or Physic Nut is an oil-bearing bush or small tree belonging to the family of *Euphorbiaceae* originated from Central and South America but now growing in tropical and subtropical zones around the world such as in parts of Africa, Asia and India (ROETTGER – JOERDENS (2007), p. 2, MUYS et al. (2007), p. 3).

Its climatic requirements for cultivation comprise altitudes from 0 – 1500 m.a.s.l., whereby 0 – 500 m.a.s.l. are most favourable for intensive production, average annual temperatures of more than 20 °C, precipitation ranging from 250 – 2000 mm per year and pH-values of the soil between 5.2 and 8.5. jatropha tolerates short periods of frost but does not resist to water logging (ROETTGER – JOERDENS (2007), pp. 2-7).

The tree can reach up to 8 meters of height. It is easy to establish, grows quickly, and produces seeds up to three times a year yielding up to 15 tons[63] of fruits per hectare with seeds containing 23-45 % non edible (toxic) oil of good quality[64] (JONGSCHAAP et al. (2007), p. 17, VAN EIJCK et al (2008), p. 6). Although single trees reach the age of 50 years (VAN EIJCK et

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[63] Data concerning yields is highly varying. According to www.jatrophabiodiesel.org the maximum yields can vary between 1.1 and 12.5 tons (NO AUTHOR (2008a).

[64] The physical and chemical properties of Jatropha oil converted into biodiesel meet the official international standards for the product – see Appendix (Table VI) – (FRANCIS et al (2005), p. 18).

al. (2008), p. 6), if jatropha is cultivated commercially, the duration of a plantation might be at best around 20 years or even less (OUWENS et al. (2007), p. 5). In general jatropha is said to be pest and disease resistant due to its toxic content (FRANCIS et al (2005), p. 18). However, this may apply to single observations of singular and solitary trees but not to the professional cultivation of jatropha as already been reported.[65] Moreover, the plant is very drought resistant[66], well adapted to tropical and semi-arid regions, undemanding concerning the type of land to be grown on – it grows on marginal, degraded, and deforested land with low nutrient content –, and even capable to reclaim problematic lands, to combat desertification by restoring the vegetative cover in degraded areas, and to prevent and control erosion due to its unique root architecture of one taproot and four laterals (MUYS et al. (2007), p. 14, HELLER (1996), p. 10). Due to its toxicity it is not browsed by animals and therefore has traditionally been used as a hedge to protect the agricultural field (WIESENHÜTTER (2003), p. 3).

Besides the aforementioned functions and various traditional applications, such as medicinal (e. g. rheumatism or skin diseases), conversion into soap, and the direct use in cooking stoves and oil lamps, the inedible oil of the jatropha seeds can be used as biofuel for diesel engines, either in its pure form or after conversion into biodiesel (VAN EIJCK et al. (2008), p. 6, WIESENHHÜTTER (2003), p. 3). The jatropha production chain also results in some valuable by-products such as seed cake, fruit husks and glycerine (ACHTEN et al. (2007), pp. 283-85). Figure 9 illustrates the Jatropha production chain.

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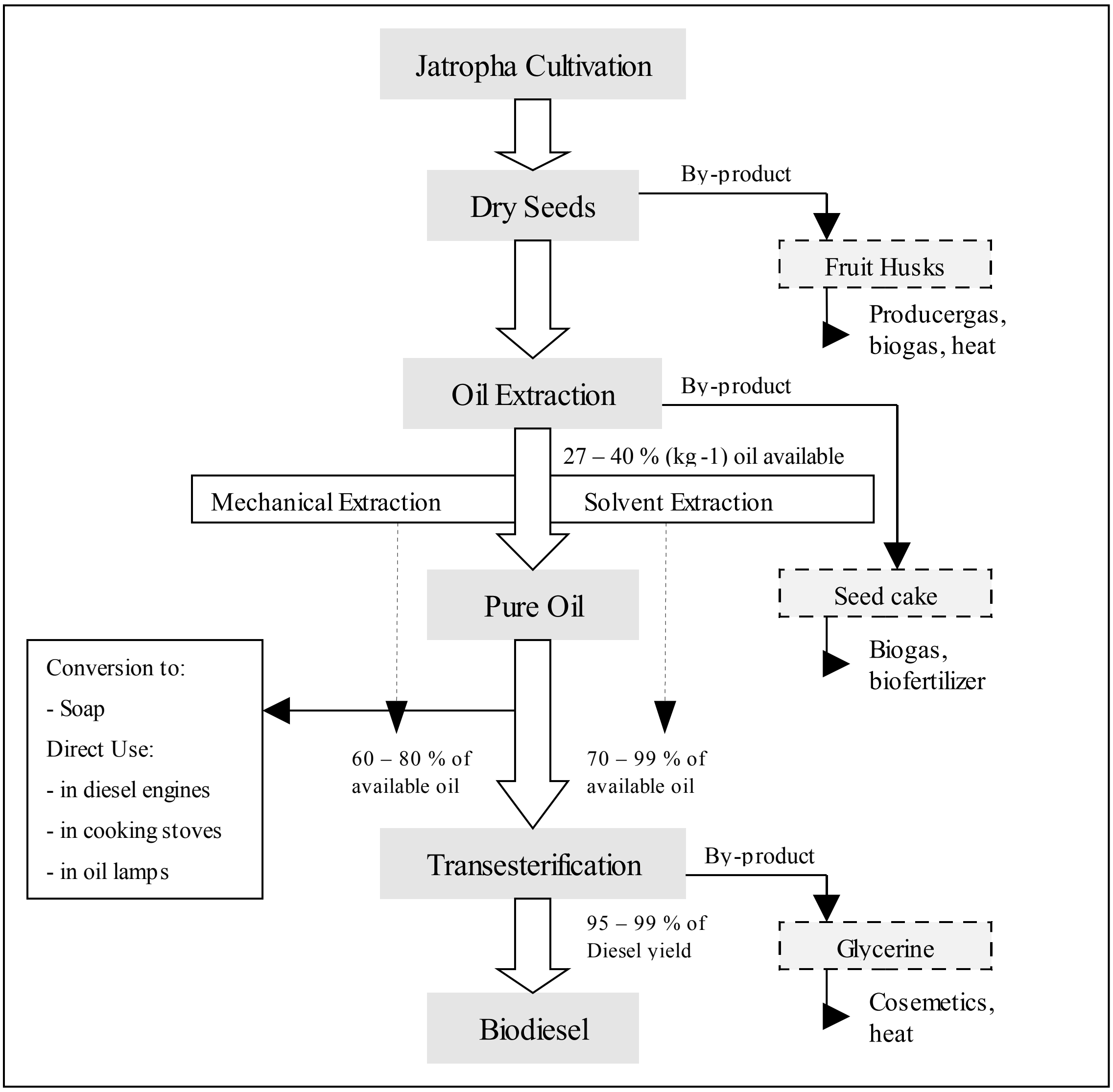
[65] Especially under humid conditions serious problems with fungi, viruses and attack of insects as well as diseases such as ‘collar rot’ or ‘root rot’, already occured (JONGSCHAAP et al (2007), p. 23).

[66] Jatropha can resist up to 8 months of drought (FairTradeFuel AG (2008).

Figure 9: The Jatropha Production Chain



Source: Own illustration, following VAN EIJCK et al. (2008), p. 6, ACHTEN et al., (2007), p. 285.

Due to its excellent characteristics providing several ecologic and socio-economic benefits in recent years jatropha has generated a growing interest as a source of renewable energy (OUWENS et al. (2007), p. 1).

As it is capable of recovering land that has already been affected by desertification, deforestation, and degradation, biodiversity can be enriched while additional CO_2 is sequestrated (DE LA VEGA LOZANO (no year) p. 11). Used as biofuel jatropha oil lowers the demand for fossil energy. This implies that CO_2 emissions and at the same time the dependency on and the expenditures for fossil fuel imports are reduced. Hence, energy security is enhanced (FRANCIS et al. (2005), p. 22). These relationships additionally include a dual potential of jatropha to attract carbon credits from the CDM market as it can be simultaneously used for both, afforestation/reforestation and energy projects (ACHTEN et al. (2007), p. 289).[67]

From the social perspective it could be considered to be an employment source, as its cultivation, from the raising of the plant over its maintenance to oil extraction – at least if done mechanically by manual ram-presses, for example –, is very labour-intensive In this manner jatropha can help improving the employment situation in rural areas, combating poverty and encouraging rural development (ROETTGER – JOERDENS (2007a), p. 13), e. g. by being used for electricity generation in isolated areas not having any access to basic services (ARÉVALO et al. (2007), p. 38). Given that the production of the tree does not replace food production food security is not affected negatively which is not a necessary consequence as it can be grown on any kind of land (ROETTGER – JOERDENS (2007a), p. 13).

5.3.2 Environmental Impact

5.3.2.1 Energy Balance

Considering all end- and by-products (Figure 9) the energy balances of a low-input as well as of an intensive cultivation of jatropha are both positive but with a worse energy balance in the latter case. That means that the intensive cultivation relative to energy outputs requires higher amounts of energy inputs embodied by fertilizers and irrigation and therefore, did not pay off in terms of energy efficiency gains. This result has to be seen against the background of knowledge gaps currently still existing with respect to jatropha and its cultivation (ACHTEN et al. (2007), p. 284). Data collected concerning growth, yields and input requirements still show a high variability. Therefore, at this stage it is challenging to determine optimal management practices which are required to improve the energy balance (FRANCIS et al. (2005), p. 19).

This is due to several reasons such as an insufficient systematic selection of genetic materials for different agro-climatic situations applied so far – especially with regard to marginal land (ACHTEN et al. (2007), p. 284)[68].

The study realized by PRUEKSAKORN et al. (2006), which assesses the effects of jatropha-based biodiesel production with respect to its GHG emissions and energy balance, shows that within the value chain – from planting the tree to the production of biodiesel – the transesteri-

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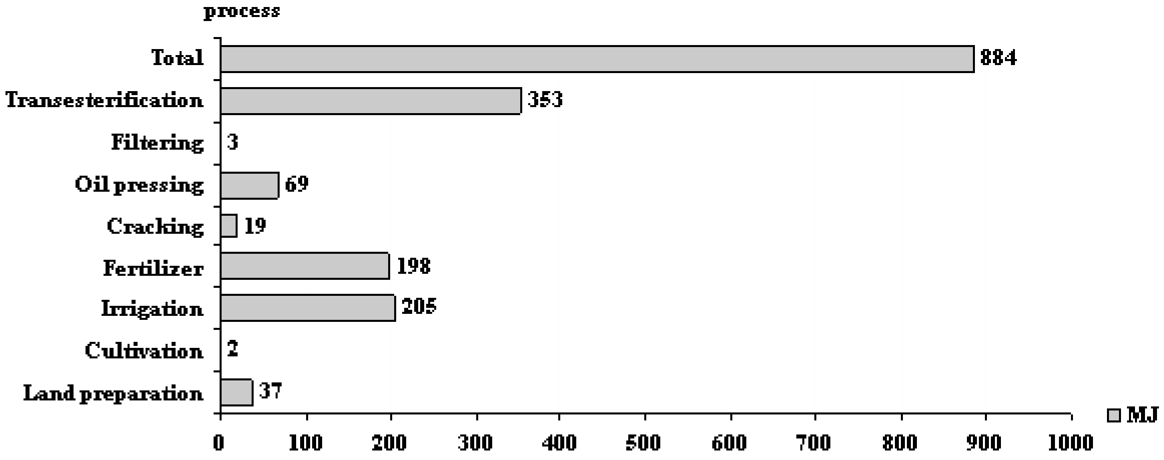
[67] In the first project type mentioned an increased carbon sequestration while in the latter the substitution of fossil fuels is required to obtain carbon credits (ACHTEN et al. (2007), p. 289)

[68] Particularly against the background that jatropha is hyped for its characteristic to reclaim marginal land.

fication process is the biggest while cultivation is the lowest contributor to energy consumption – with 0.353 GJ[69] and 0.002 GJ, respectively.[70] This implies that at least in the case of Peru the use of pure oil improves the energy balance significantly and for that reason should be preferred.[71]

Figure 10: Energy Consumption when producing 1 GJ of Jatropha Biodiesel and Co-products



Source: PRUEKSAKORN et al. (2006), p. 4.

The energy gain from jatropha does not only rely on the use of biodiesel or the pure oil but also on the use of the by-products such as the use of coat and leaves, seedcake for fertilizer, glycerine for the cosmetic industry, fruit husks for gasification or the use of wood – which comes from annual pruning of jatropha – to produce heat. Figure 16 shows the energy output from the whole process of biodiesel production and its by-products made of jatropha. The lowest contribution to the energy generated (1.0 GJ) comes from biodiesel while the highest energy of 10.289 GJ from wood.

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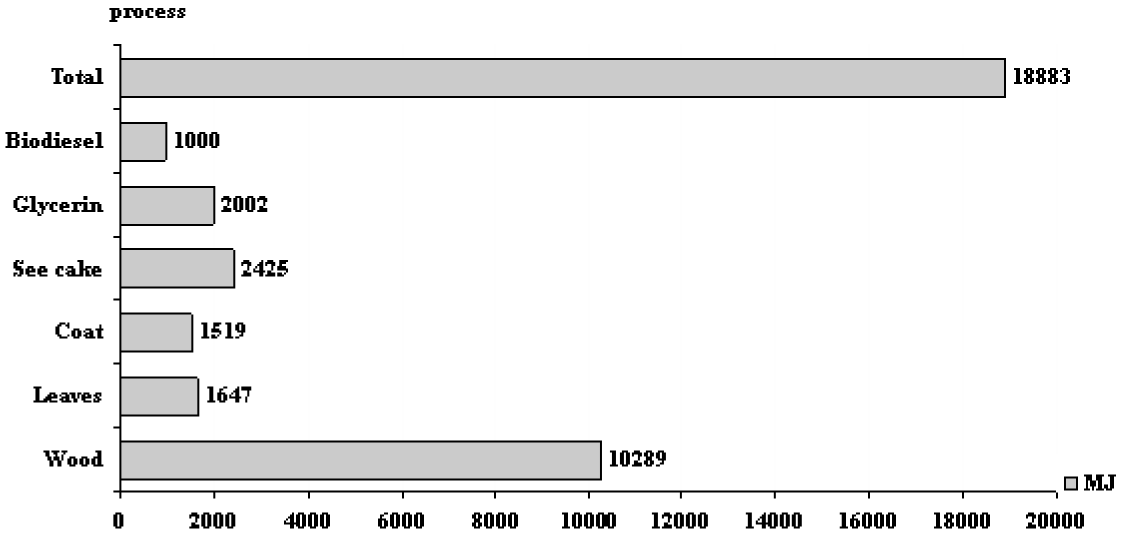
[69] The Functional Unit (FU) used in this study is 1 GJ equivalent of liquid fuel (PRUEKSAKORN et al. (2006), p. 1)

[70] Figure 15 shows the energy consumption in each process to produce biodiesel from Jatropha. The total energy consumption is around 0.884 GJ.

[71] The pure oil is less energy efficient and can cause problems to newer diesel engines. If the pure oil is used in older *diesel* engines fewer problems exist, and it can be used for irrigation pumps and generators. If applied in these older diesel engines the lower energy efficiency will probably be of no significance compared to transesterified oil (ACHTEN et al. (2007), p. 284).

Figure 11: Energy Production when producing 1 GJ of Jatropha Biodiesel and Co-products



Source: PRUEKSAKORN et al. (2006), p. 4.

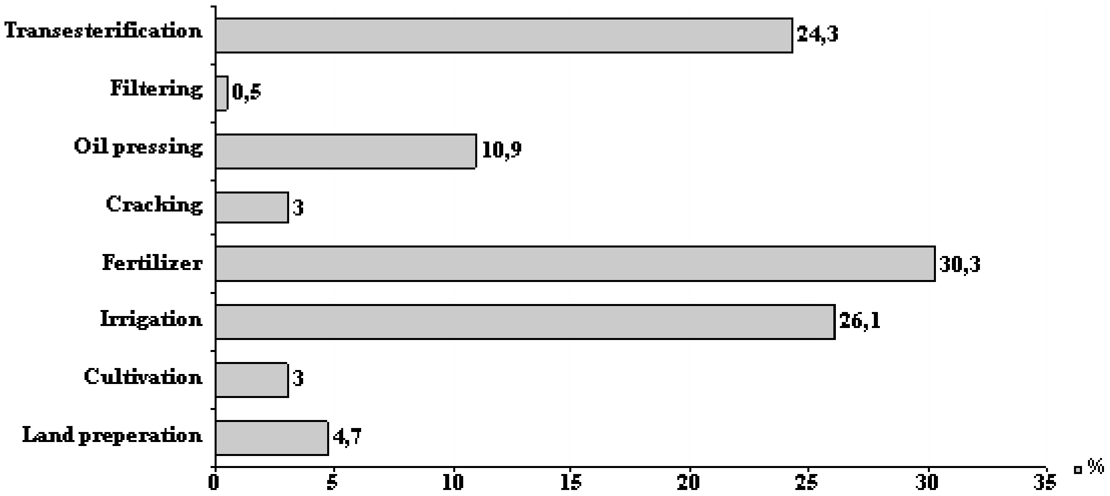
The energy balance of the whole process of biodiesel production from jatropha can be highly positive with around 21 to 1 (see Figure 10 and 11) - if also considering the energetic use of the by- and side-product next to the crude Jatropha oil. However, the positive energy balance is mainly due to the energetic use of all by-products and "…the feasibility (economical, environmental, infrastructural) of using these by-products efficiently in practice is still under debate and is much dependant on the organization of the production system and local conditions in practice and potential"(ACHTEN et al. (2007), p. 286). Hence, without possibly being able to make energetic use of the by-products the energy balance becomes less positive. The positive energy balance can also become (even) less positive after transesterification, with an increasing intensification and mechanisation of the production cycle, if biodiesel or maybe by-products are shipped to remote markets such as Europe and also energy consumption due to transportation needs throughout the whole production chain can be significant in case of strong centralisation of biodiesel processing units (oil extraction and transesterification) (MUYS et al. (2007), p. 41).

5.3.2.2 Greenhouse Gas Balance

GHG emissions from jatropha are occurring all along the production chain – from land preparation to end-use. In case of the utilisation as biodiesel as well as in the case of conventional diesel around 90 % of GHG emissions are dedicated to the end-use itself while the remaining percentage is mainly allocated to the production phase and only to a small proportion to the transport of biodiesel (Figure 13) (PRUEKSAKORN et al. (2006), p. 5).

Within the production phase GHGs are caused due to electricity production for cracking, oil pressing, filtering and fertilization as well as to diesel consumption for land preparation, cultivation and irrigation and further to the process of transesterification, whereby fertilizer production and application[72] together with irrigation as well as transesterification[73] make the most considerable contributions with around 30, 26, and 24 %, respectively. Figure 12 shows the emissions of GHG by process.

Figure 12: Emissions of GHG according to each Process



Source: PRUEKSAKORN et al. (2006), p. 5).

Considering each evaluated life-cycle and under the assumption that the oil is used locally the GHG emissions outgoing from jatropha-based biodiesel are less than compared to fossil diesel. The total global warming potential of (jatropha biodiesel production and use is only 23 % of conventional diesel.[74] The main reason of for this positive result is that CO_2 emitted combusting biodiesel is considered to be GHG-neutral since it was absorbed earlier during plant

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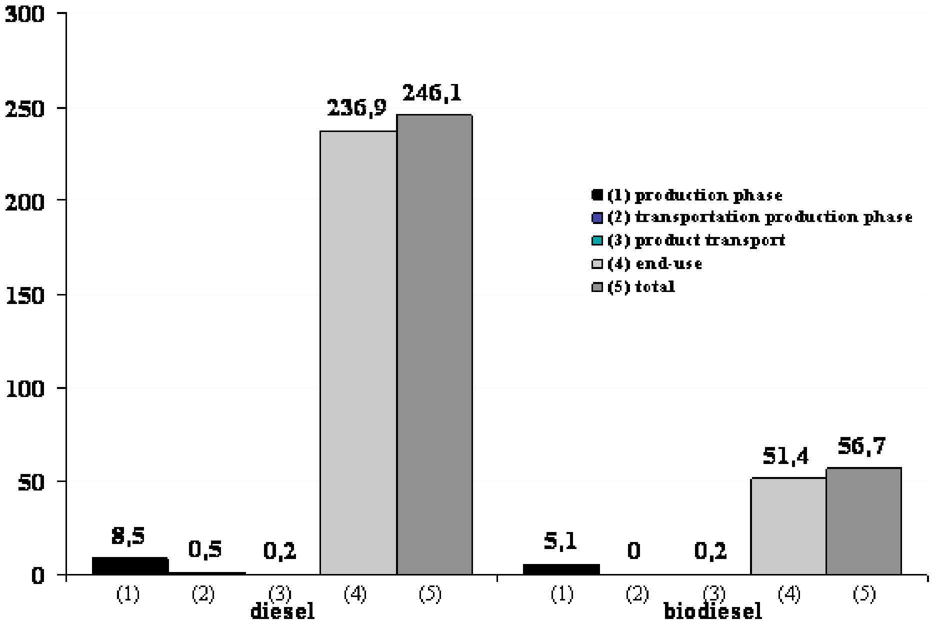
[72] „That is because N-compounds from the process of N fertilizer production and use are the source of N_2O creation which is a highly potent GHG.“ (PRUEKSAKORN et al. (2006), p. 4)

[73] That means that if the resulting pure oil from Jatropha is used in diesel engines, the GHG balance becomes even more positive.

[74] According to FRANCIS et al (2005) the CO_2 emissions of jatropha are around 15 % less than compared to conventional diesel fuel (FRANCIS et al. (2005), p. 19)

growth.[75] However, the expected positive GHG balance of jatropha based biodiesel could be deteriorated if the by-products was not used energetically, an increasing amount of nitrogen was used for fertilization, and if the resulting biodiesel is transported over longer distances, e. g. shipped to the U.S. or even the European Union (MUYS et al. (2007), p. 39).

Figure 13: Comparison of Life-Cycle Emissions of GHG according to each Process



Source: own illustration, following PRUEKSAKORN et al. (2006), p. 5.

Another very decisive aspect to consider in the context of the GHG balance is the impact caused by land-use changes for the cultivation of jatropha. If wasteland is replaced for jatropha the GHG balance even improves due to a higher carbon sequestration afterwards. If, additionally, the seedcake is used as a soil amendment, carbon absorption by the soil is increased, as well (ACHTEN et al. (2007), p. 286). In case that rainforest and in particular peat land is logged and used for the production of jatropha the GHG emissions caused will by far not be compensated by the carbon offset in the new jatropha plantation (SCHMITZ (2007), p. 1474).

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[75] Figure 13 shows the comparison of the life cycle GHG emissions of biodiesel and diesel.

5.3.2.3 Impact on Ecosystems

In order to be able to assess the land use impact of a new plantation it has to be compared with the impacts caused by the former land use (MUYS et al. (2007), p. 39). In the framework of environmental impacts due to the conversion of wasteland and forest land, respectively, into jatropha plantations the potential effects are distinguished into impacts on (a) the ecosystem structure and (b) the functioning of ecosystems.

An improvement in vegetation structure and biodiversity is expected if wasteland[76] is replaced for the cultivation of jatropha (FRANCIS et al. (2005), p. 21). By contrast, a reverse effect is caused in case that undisturbed natural ecosystems are converted (ACHTEN et al. (2007), p. 287) into plantations.

The expected positive impacts compared to wasteland if replaced by jatropha include a higher biomass production, a better vegetative ground cover as well as a possible increase of habitat value. The intensity and the direction of the potential positive impacts are strongly correlated with the type of cultivation (FRANCIS et al. (2005), p. 20, ACHTEN et al. (2007), p. 287). Against this, in case of monocultures the positive impacts can be partly or even overcompensated due to the dominance of negative effects accompanied with a more intensive application of fertilizers, irrigation, biocides[77], and soil work (ACHTEN et al. (2007), p. 287).

The small-scale cultivation of jatropha as well as its use as hedges is generally linked with positive impacts as both potentially create more gradients and landscape connectivity, diversity sinks and corridors. Nonetheless, fertilizer is required in order to achieve stable and high yields and to prevent soil exhaustion of wastelands. Again, further quantitative research in nutrient cycles and the optimisation of inputs is necessary (ACHTEN et al. (2007), p. 287).

On the one hand using the seedcake as fertilizer reduces the demand for chemical substances, but on the other hand some reports document invasive characteristics of jatropha, such as the risk of phytotoxicity, expressed as reduced germination that might result from the manuring by means of the seedcake. Therefore, further research should also focus on these effects on

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[76] It should be noted that the definition of 'wasteland' is rather ambiguous, and should not be confused with the term 'marginal soils' or 'marginal lands'. The use of the term 'wasteland' can indicate either unoccupied areas or areas where land ownership is not clear, whereas 'marginal soils' or 'marginal lands' are applied to describe areas with unsuitable conditions for cop production due to soil and climate constraints (JONGSCHAAP et al (2007), p. 6).

[77] In general Jatropha is expected to have a relatively low need of biocides compared to other crops (MUYS et al. (2007), p. 38).

local ecosystems (HELLER (1996), p. 23, KUEFFER et al. (2004), p. 9, MUYS et al. (2007), p. 38).

Besides, several ecosystem functions can be improved by cultivating jatropha. Propagating the plant generatively by seeds instead of vegetatively by cuttings can help preventing and controlling erosion as well as it is very promising with respect to superficial soil and soil stabilization itself. This is due to the unique root architecture with one taproot and four laterals which does not evolve in case of vegetative propagation (JONGSCHAAP et al. (2007), p. 5).

By leaving the shed leaves and the weeded growth as mulch and, furthermore, using the seedcake as biofertilizer[78] the soil can additionally be enriched with organic material which implicates an improvement of the soil structure and the water-holding capacity (ACHTEN et al. (2007), p. 287, JONGSCHAAP et al. (2007), p. 16). In general the cultivation of jatropha is expected to have mostly positive impacts on the fertility, stability, and the carbon sequestration of soils, especially in case of wasteland replacement, but again the strength of the effects depends much on the type of cultivation applied (MUYS et al. (2007), p. 38).

If a more intensive cultivation is employed – such as higher amounts of fertilizers or the use of heavy machinery, causing soil compaction, for instance – many positive impacts can be reduced (MUYS et al. (2007), p. 38). Moreover, it is almost dispensable to mention that the replacement of natural forest will have the most significant negative impact on the soil – affecting GHG emissions, soil fertility, soil structure and water-holding capacity (ACHTEN et al. (2007), p. 287).

With respect to the water balance a positive on site as well as a negative off site impact might occur simultaneously. On the one hand, jatropha enhances the ecosystem's capability of controlling the water cycle as the strong increase in evapotranspiration (ET) leads to a reduction of surface runoff and a higher infiltration capacity. On the other hand, a decline in water availability downstream can result if the ET of jatropha is higher than the ET of the natural vegetation. In order to assess the impact on the water balance, more research is needed (ACHTEN et al. (2007), p. 288, JONGSCHAAP et al. (2007), p. 7, MUYS et al. (2007), p. 38).

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[78] Even though the use of the seed cake as fertilizer is mainly expected to result in positive effects, its toxic character demands further investigations on long-term effects to soil, and especially to its possible use for edible crops, as such do still not exist (ACHTEN et al. (2007), p. 287).

5.3.3 Socio-Economic Impact

At the moment, little is known about socio economic impacts and further research is needed with respect to the cultivation of jatropha (ACHTEN et al. (2007), p. 288). Therefore, only basic aspects will be discussed below.

It is to be mentioned positively, that jatropha is a very labour-intensive crop. Especially the harvest is very demanding since a mechanical harvesting is linked with problems due to the fact that the fruits are continuously ripening throughout the year and have to be harvested at maturity. Hence, jatropha is believed to create substantial job opportunities and, therefore, to generate income for the local poor and foster rural development. Since the availability of jobs alone does not imply the incidence of the aforementioned potential benefits, it has to be ensured that new jobs comply with national and international standards such as the international labour standards provided by the ILO[79] (RIJSENBEEK et al. (2007), pp. 4, 9).

Another factor influencing the socio-economic potential of jatropha refers to the design of the production chain, which can be distinguished into large-scale, centralised estates working with outgrowers on the one hand and a decentralised set-up on the other hand. The latter one seems to be more promising in order to use the end- and by-products resulting for local consumption, and thus, also contributing to foster rural development, whereas it is not assured that decentralised set-ups profit of these opportunities due to the local culture as well as a possible lack of skills and knowledge. With regards to the centralised set-up increasing economies of scale from the income of both, biodiesel and the by-products can be expected (FRANCIS et al. (2005), p. 20). By means of job and income generation and capability support rural development is enhanced, as well, but this can only be ensured if the company in consideration complies with national and international labour standards – as already mentioned before (ACHTEN et al. (2007), p. 289).

On the other hand, due to land-use pressure in rural areas, concerns have risen that the cultivation of jatropha could lead to a displacement of food production. This assumption seems to be well reasoned as the prices for biodiesel continue to rise. Of course this problem will not occur if jatropha cultivation takes place on areas not suitable for edible crops.

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[79] For more information about the ILO and their standards: http://www.ilo.org.

Moreover, the toxic content of jatropha seeds, oil and seedcake can cause negative impacts to human health which is not excludable as workers` skin can easily mingle with the oil (JONGSCHAAP et al. (2007), p. 32).

Regardless of the fact that the investments needed for a decentralised production chain are smaller than those for a centralised one, currently both would face a financial risk due to uncertainties still existing concerning the (highly varying) annual seed yield and its responsiveness to fertilizer and irrigation use (ACHTEN et al. (2007), p. 289).

5.3.4 Conclusions

Due to a lack of reliable data it is challenging to judge/assess the sustainability of cultivating jatropha. The energy and GHG balances are assumed to be positive but significantly dependent first, on the type of land-use – marginal wasteland or natural forest –, and second, on the type of cultivation, respectively, its intensity. The impacts on soils, biodiversity, and on water balances are partly uncertain. In case of converting wasteland effects seems to be acceptable or even positive whereas converting natural forest would be accompanied by unacceptable consequences (FRANCIS et al. (2005), p. 22). As long as uncertainties still remain, small scale farmers should not invest in jatropha. There is an urgent need for further research with respect to seed yields, yield responsiveness to inputs, land-use impacts, and systematic selection of the best suitable genetic material (ACHTEN et al. (2007), p. 289).

5.4 Jatropha Case Study – San Martin, Peru

5.4.1 DED-Project

5.4.1.1 Outlines of the Project

In Lima, around 40,000 buses are in service, thereby consuming around 2 million litres of diesel a day. Against the background of continuously increasing diesel prices and the fact that Peru imports more than two thirds of its domestic diesel consumption (see Section 5.1.6) on the one hand as well as serious environmental problems, climate change and impacts on human health resulting of diesel combustion on the other hand, since June 2005 the DED governs the pilot phase to the project “vegetable oil as a substitute for diesel”.[80]

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[80] The DED is the executive body as well as the co-financier of the project. Further public partners are the Common Fund for Commodities (CFC) which serves as the principal financier, the FAO (Supervisor) and the GTZ.

The project aims at promoting a sustainable development principally focussing on the improvement of the small farmer's situation. This shall be realised by means of promoting the cultivation of the oil crop jatropha. Therefore, a value chain approach has been applied as it was assumed to be most suitable. This concept should guarantee a commercial favourable relation of all stakeholders involved: agricultural producers, vegetable oil producers, and consumers.

The small farmer produces jatropha fruits and sells the seeds at the farm gate to the vegetable oil producer which transforms the seed into pure vegetable oil and jatropha meal (seed cake). The oil is used as a fuel in buses of the private Peruvian transport company CALIFORNIA from Lima. After the required technical modification of the diesel engines[81] diesel , pure oil, and any blending of both can be utilized. The remaining jatropha meal is further sold as a protein rich product to the healthy food sector. The public transport services constitute a guaranteed market for jatropha oil due to its huge vegetable oil demand for fuel use.

Currently, the project is realized in four different test locations in the Peruvian Amazonia covering around 100 hectares of jatropha plantations: in the department of San Martín Picota and Leoncio Prado, Motupe in Lambayeque, and Ocucaje, in the department of Ica (see Figure 14).

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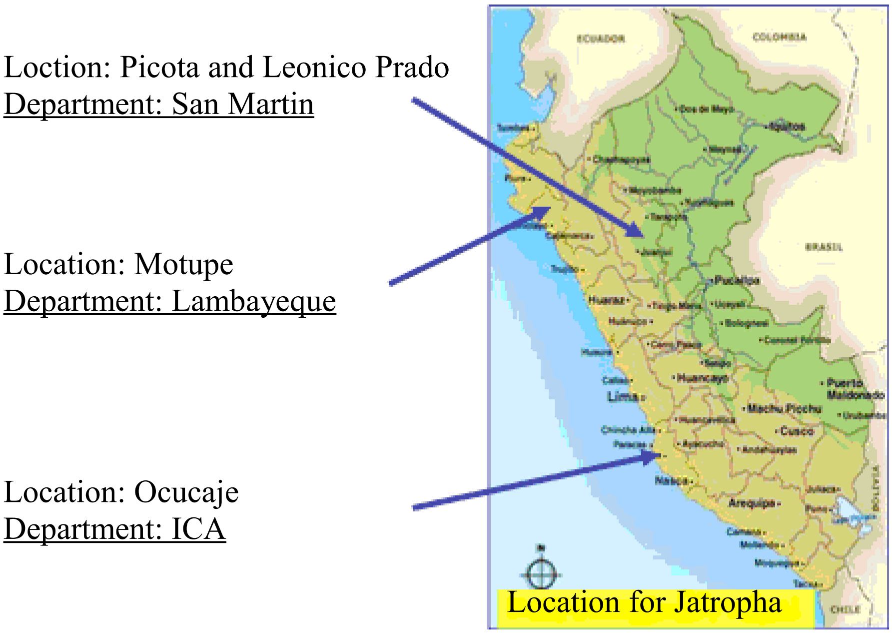
[81] This is performed by the German company Vereinigte Werkstätten für Pflanzenöltechnologie (VWP) which cooperates with the pilot project.

Figure 14: DED – Jatropha Project Locations in Peru



Source: Figure received by the DED Lima, Peru (2008).

In the framework of the undertaking the DED is supporting small farmers in each of these regions that show interest in jatropha, by providing agricultural support concerning the entire cultivation scheme, including financing schemes and purchasing contracts guaranteeing fixed prices paid by the vegetable oil companies. Each location has its own oil production plant with a capacity for processing 100 kg of seeds per hour. A decentralized organisation type is purposely promoted by the DED, as it is assumed to be more favourable in terms of rural development.

5.4.1.2 DED Results - experience and expectation

The following information regarding the project results refer to Leoncio Prado, San Martín. All information was obtained directly from the DED office in Lima and exclusively by personal communication with project members.[82]

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[82] These members include the project supervisor Mr. SEIDLER, his project assistant Mr. SKODDOW and Mr. GIL ÍOS, a technical assistant supporting the small farmers on-site. For the following the members are denoted by SKODDOW et al. (2008).

Data obtained are based on the plantation of 2,500 plants per hectare with a spacing of 2m x 2m.[83] In the first and second year yields correspond to 0.9 and 2.4 tons per hectare, respectively. The current project year is expected to reach 4.2 tons of seeds[84] per hectare before reaching the maximum yield of 6 tons from the fourth year onwards (SKODDOW et al. (2008)).[85] The price per ton of seeds guaranteed to the farmer is US$ 180.

Besides the seeds, the planting of one hectare requires approximately 3.75 t of compost fertilizer. The aggregate investment cost is around US $ 1200[86] arising from land preparation, fertilizer use, and for the jatropha seeds as well the cuttings during the first year by which the potential yield is expected to increase up to 7 instead of 1.5 tons without cuttings. After the first year of the crop no estimable amounts of fertilizers are expected to be required. The same applies to pesticides, except for the infestation of the seedling by insects at the initial stage of growth no diseases or pests are reported, yet. Therefore, according to SKODDOW et al. (2008), costs for fertilizer use or pest and disease control are not considered in the context of annual operative costs, that – from the second year[87] onwards – value at approximately US$ 300/ha[88] for weeding[89] and harvesting activities. Due to the sub-tropical climate weeding as well as harvesting[90] occurs almost throughout the year with higher labour demands during wet seasons and less or even no demand in dry seasons. For the high natural precipitation levels irrigation costs are negligibly low (SKODDOW et al. (2008)). Except these costs no other costs are considered.

At present the third year of the project has begun. Until the end of the project – around June 2009 – at least 100 buses are expected to have been adapted to jatropha-based biodiesel. At the moment there have not been any adoptions, yet. First a stable supply of jatropha oil has to be assured. These estimations still have to be confirmed, as yield data has only been verified for the first two years. Furthermore, neither data with respect to energy or GHG balances nor

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[83] Currently the DED tries to extend to 10,000 plants per hectare (SKODDOW et al. (2008)).

[84] For the following the value of tons with respect to jatrpoha yield refers only to the weight of the seeds.

[85] This is in contrast to the prevalent opinion reported in general as the yield is said not to reach its maximum until the fifth year (e.g. http://jatrophabiodiesel.org/).

[86] Investment and operative costs applied for the CBA and received by the DED are assessed to be underestimated by the author. However, as the DED itself based its calculations on these figures, they are further used in this single section. In Section 5.4 figures used are adjusted to the best of the authors knowledge due to own research and the informations given by the DED.

[87] Actually the annual operative costs of US$ 300 occure each year. However, the DED added them to the investment costs arising in the first year.

[88] See Fn. 93.

[89] Jatropha already begins flowering in the initial year.

[90] As ripening of Jatropha fruits do not occure simultaneously, harvesting occurs at different times of the year.

concerning other basic ecological and socio-economic issues could be provided by the DED so far, as these are not yet available.

However, the DED undertook a CBA on the basis of the aforementioned data, with very promising results. Presuming a period of 20 years, an interest and discount rate of 10 and 8 %, respectively, as well as a six-year payback period for the credit required due to the relatively high investment costs, the net present value (NPV) calculated equals US$ 5,047/ha. The results of the small farmers` CBA are summarised in Table 17[91].

Table 17: Costs and Benefits of the Small Farmer

Costs and Benefits of the small farmer[a]			
Costs[b]		US$/ha	
Investment Costs			1 200
Annual Operative Cost (2nd onwards)			300
Revenues			
Year	Yield (tons/ha)	US$/ton	Revenue (US$/ha)
1	0.9	180	162
2	2.4	180	432
3	4.2	180	810
4	6.	180	1 080
5-20	6.	180	1 080
Period evaluation (years)			20
Interest Rate of discount			8 %
Net Present Value (US $/ha)			5 047

[a] For a detailed overview of the calculations, see Appendix I (Table VII)

[b] Costs are based on estimations undertaken during the initial phase of jatropha cultivation (SKODDOW et al. (2008)).

5.4.2 Economic Theory – Profit Maximization

Within (neo-) classic theory the concept of *Homo Oeconomicus* implies that any decision made by individuals is aiming at private profit maximisation. This assumption is formally described by following equation,

$$\pi = \sum_{i=1}^{n} p_i y_i - \sum_{j=1}^{m} w_j x_j \overset{!}{=} \text{Max.} \tag{1}$$

The first expression stands for the aggregate revenues of a household or company and is defined as the sum of all prices p for product *i* (1, …, n), each of them multiplied by the cor-

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[91] For a detailed overview of the calculation as well as the CBAs of the remaining stakeholders belonging to the vegetable oil and the public transport sector see Appendix I (Tables VIII – XI).

responding output y_i. The latter term represents the costs (e. g. production costs) which are calculated by adding up each price w for input *j* (1, …, m) with the respective amount of input(s) x_j required (VARIAN (1999), p. 307).

The Peruvian farmers subject to this analysis are expected to behave according to the assumptions made above. Thus, equation (1) will serve as the basis for farm-household decisions.

5.4.3 Model Specifications

5.4.3.1 Research Hypothesis

Based on the economic theory presented in the previous Section, the objective of this study is to determine the sustainable production (level) of jatropha, as well as on recent research concerning the cultivation of the plant in the region of San Martín, Peru the following core hypothesis is derived:

The cultivation of jatropha benefits the farmers in the region of San Martin, Peru.

Of this base hypothesis two cases will be differentiated:

1. It is beneficiary to farmers to cultivate jatropha in addition to their current optimal production structure on deforested land

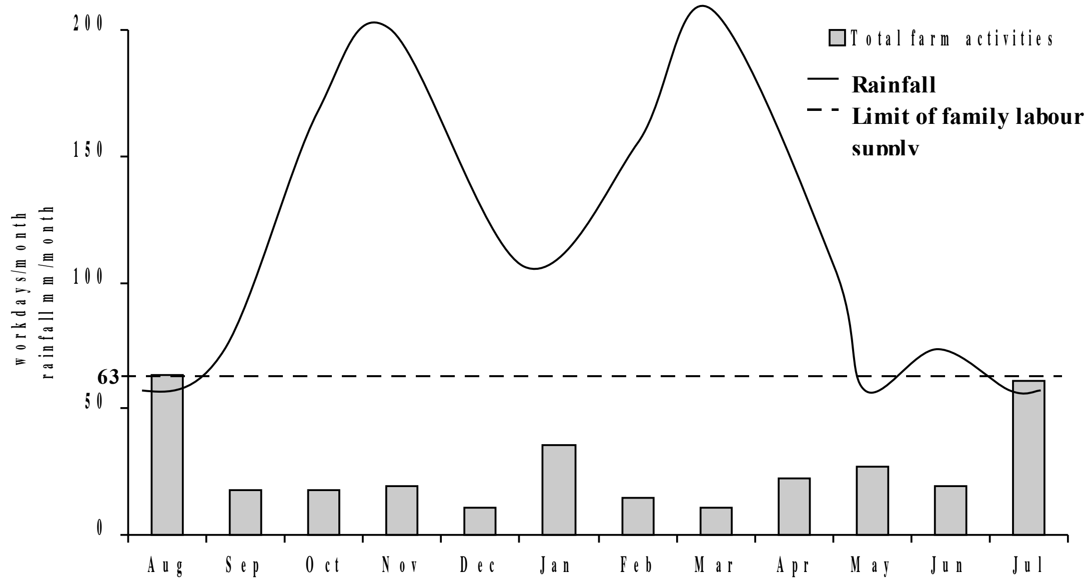
2. It is even more beneficiary to farmers to cultivate jatropha being allowed to reduce annual crop production up to the respective subsistence level

5.4.3.2 The Research Site

Currently the DED is testing the cultivation of jatropha on deforested areas in the province of Leoncio Prado in the region of San Martín, Peru (see Section 5.4.1.1), which is one of three Amazon regions. Due to a lack of data with respect to the farming activities in the aforementioned province, Pucallpa was chosen alternatively as it is an ideal forest margin benchmark site for both, the bio-physical characteristics as well as the patterns of land use are likely to be similar to many regions in the Amazon (WHITE et al. (2005), p. 14). In correspondence with the aforementioned explanations a study by WHITE et al. (2005a) including the description of the farming activities in Pucallpa serves as the basis for this analysis.

Pucallpa belongs to the department Ucayali, Peru. It is located in the forest margins of the western Amazon basin and is located 150 m.a.s.l. (WHITE et al. (2005), p. 14). The mean annual temperature is 25 °C, coinciding with an average rainfall of approximately 1,700 mm per year with an unbalanced bi-modal pattern.[92] The wet seasons are from February-April and from October-December, the dry seasons from May to September as well as in January (Figure 15).

Figure 15: Labour Requirements of a typical Bush Fallow Farm and monthly Rainfall



Source: own illustration, following WHITE et al. (2005a), p. 188.

Agriculture, hunting and forest activities produce 31 % of the gross regional product. The destination of a majority of the farm products is the city of Pucallpa itself, which has a population of about 250,000 inhabitants. Pucallpa is characterized by a variety of farmer types and associated land uses. The farms subject to this analysis, which are identical to the reference group observed by the study of WHITE et al. (2005a) face poor local and regional infrastructural conditions. They are directly accessible only by tertiary-quality roads. Moreover, the rudimentary infrastructure network isolates the farmers from the rest of the country – not to mention any access to international markets – and increases their marketing costs. Considering that the farmers lack the availability of sufficient natural and financial resources the fact previously mentioned weighs even more. Common agricultural practices – for which most of the

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[92] In Leoncio Prado Jatropha is cultivated on fields ranging from 0 -500 m.a.s.l. The mean annual temperature is around 24 °C meeting an annual precipitation of approximately 3,300 mm.

former on-farm forest has already been replaced – comprise a mix of traditional annual crops, such as rice, maize, beans, cassava and plantain as well perennials like citrus. All crops are principally cultivated for household consumption. In order to increase soil fertility and lower the risk of weed invasion bush fallow practices are applied (WHITE et al. (2005), p. 4, WHITE et al. (2005a), p. 188).

5.4.3.3 Surveys and Data

The data set collected by WHITE et al. (2005a) by means of personal interviews and secondary sources[93] contains detailed information about the crop systems and cycles cultivated as well as baseline information of land-use dynamics and prevalent farm types. This data set is expanded by data regarding the cultivation of jatropha received by SKODDOW et al. (2008) who are taking part in the aforementioned project of the DED (see Section 5.4.1).

The average farm size of the sample is about 20 hectares of which approximately three hectares are still in high-forest while the remaining area is dedicated to following purposes, annual crops (ca. 2 ha)[94], perennial crops (ca. 0.4 ha), fallow land (ca. 7 ha) and pasture land (7.5 ha)[95]. The representative crop cycles are as follows. Rice is cultivated in the first year, followed by two consecutive years of plantain, and the same sequence is applied to maize and cassava as well as beans and cassava, respectively. The respective average crop yields per hectare and prices per ton are given in Table 18.[96]

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[93] LABARTA et al. (1998), and FUJISAKA (1997), National Agricultural Research Institute (INIA), and the Ministery of Agriculture-Ucayali.

[94] In Section 5.4.3.4. be shown that this value again does not comply with the restrictions made by the authors.

[95] Although the majority of the farmers do not even own cattle, they rather prepare pasture land in hope of being able to purchase cattle one day (WHITE et al. (2005a), p. 189).

[96] The prices provided by WHITE et al (2005a) have been adjusted in three steps. First, the $-values were converted to PS-values by applying the exchange rate of 1US$/3.50 PS presumed by the authors. Second, the resulting PS-prices were corrected by the mean inflation rate during 2000 and 2007 and in a third step converted again according to the actual exchange rate. The yield of citrus in tons per hectare was calculated by the following formula: $\text{yield}_{\text{citrus}}$ [tons/ha] = (($\text{profit}_{\text{citrus}}$ [\$] + occupied $\text{area}_{\text{citrus}}$ [ha] * total labour $\text{requirement}_{\text{citrus}}$ [workdays] * standard wage rate [\$/workday] / $\text{price}_{\text{citrus}}$ [\$/ton]) / occupied $\text{area}_{\text{citrus}}$ [ha], in numbers: $\text{yield}_{\text{citrus}}$ = ((212 + 0.42 * 137 * 2.7) / 120) / 0.42 = 7.3 tons/ha. In the case of Jatropha the yield of 5.5 tons/ha results by determining the mean yield per hectare over a period of 20 years in accordance with data received by the DED via personal communication.

Table 18: Crop Yields and Prices of Pucallpa Slash-and-Burn Farms and of Jatropha

Crop Yields and Prices of Pucallpa slash-and-burn farms and of Jatropha

Crop	Yield (t/ha)	Price (US $/t)
Rice	2.0	130
Maize	2.0	111
Bean	1.0	435
Cassava	13.0	46
Plantain	741[a]	56
Citrus	7.3	111
Jatropha (1)	5.5	180
Jatropha (2)	5.5	180
Jatropha (3)	3.7	140
Jatropha (4)	3.7	140

[a] Plantain is measured in bunches. According to SKODDOW et al. one bunch weigh 13 kg/bunch.
Source: own illustration, following WHITE et al. (2005a), p. 189.

In correspondence with the author WHITE the fertilizer and pesticide use is negligibly low for traditional crops. Therefore, on the input side special attention is paid to monthly labour requirements as illustrated in Figure 15[97]. The same applies to jatropha except for the first year, as – according to SKODDOW et al. (2008) – there is an initial investment of around US$ 1783 required for plants fertilizers, and specific tasks occurring only within the first year (see Section 5.4.1.2). On this one-time payment the actual Peruvian prime rate of 8 %[98] is deployed, and on that basis the annuity over the period of 20 years is determined. This amount of approximately US$ 182 is added to the labour costs as fixed costs.

According to SKODDOW et al. (2008), family labour is valued at US$ 4/per person/day. Although hiring labour from off-farm is neglected (see Section 5.4.3.4), temporary labour is taken into account with US$ 5 in order to be able to determine realistic labour calculate shadow prices.[99]

The labour requirements for agricultural production are varying throughout the year (Figure 15). Land preparation takes places usually during the dry months of July and August by means of slash-and-burn techniques. In August most of the annual crops except beans are

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[97] Figure 15 is the revised version of Figure 1 of WHITE et al. (2005a), p. 188. The labour demand calculated by the authors does not comply with the restrictions applied by them. The original form of the figure can be seen in Appendix I (Figure III).

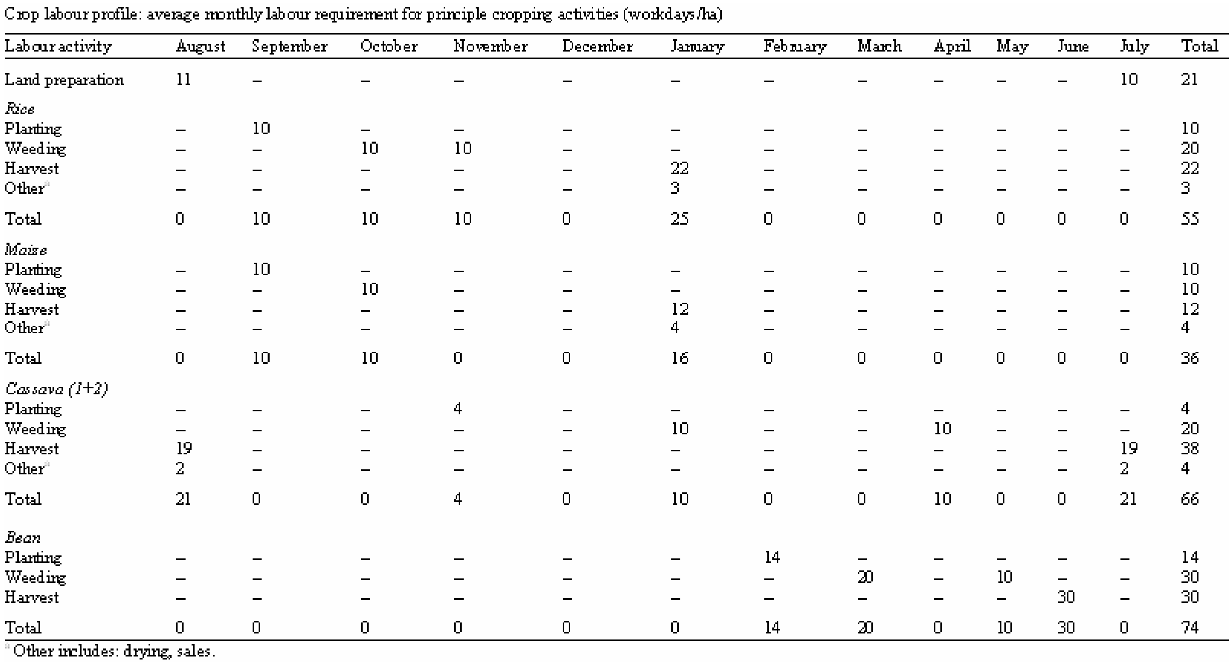
[98] The prime rate is based on information given by the DED.

[99] According SKODDOW et al., the current wage per workday is between 10 and 12 PEN. In order to calculate the results not too optimistically, the latter value will be used for temporary labour within the following analysis. Using the actual exchange rate and subtracting US$ 0.50 a day for the way to the workplace and back, rounded up familiy is valued at US$3.80.

planted and manual weed control takes place from September-October. Harvest occurs according to the respective crops in different months. In the study of WHITE et al. (2005a) the labour peak was calculated for January. Again due to the violation of the side restriction of subsistence production and the high amount of labour required for land preparation this result needs to be adjusted. In correspondence with the author for each hectare used for the cultivation of annual crops the equal size of land has to be prepared before planting[100]. The corrected labour peak occurs in August (see Figure 15).

The detailed allocation of labour requirements according to farming activities throughout the year are given in Table 19. The main tasks for land preparation as well as for all cultivated crops are tabulated in workdays per hectare. While citrus, plantain and jatropha have a much more consistent need for labour the remaining crops have a more specific labour demand in certain months. As already mentioned above land preparation is only restricted to the months of July and August, near the end of the dry season. The commercialization takes place in March and from April to June for annual and perennial crops, respectively.

Table 19: Crop Labour Profile



Crop labour profile: average monthly labour requirement for principle cropping activities (workdays/ha)

Labour activity	August	September	October	November	December	January	February	March	April	May	June	July	Total
Land preparation	11	–	–	–	–	–	–	–	–	–	–	10	21
Rice													
Planting	–	10	–	–	–	–	–	–	–	–	–	–	10
Weeding	–	–	10	10	–	–	–	–	–	–	–	–	20
Harvest	–	–	–	–	–	22	–	–	–	–	–	–	22
Other[a]	–	–	–	–	–	3	–	–	–	–	–	–	3
Total	0	10	10	10	0	25	0	0	0	0	0	0	55
Maize													
Planting	–	10	–	–	–	–	–	–	–	–	–	–	10
Weeding	–	–	10	–	–	–	–	–	–	–	–	–	10
Harvest	–	–	–	–	–	12	–	–	–	–	–	–	12
Other[a]	–	–	–	–	–	4	–	–	–	–	–	–	4
Total	0	10	10	0	0	16	0	0	0	0	0	0	36
Cassava (1+2)													
Planting	–	–	–	4	–	–	–	–	–	–	–	–	4
Weeding	–	–	–	–	–	10	–	–	10	–	–	–	20
Harvest	19	–	–	–	–	–	–	–	–	–	–	19	38
Other[a]	2	–	–	–	–	–	–	–	–	–	–	2	4
Total	21	0	0	4	0	10	0	0	10	0	0	21	66
Bean													
Planting	–	–	–	–	–	–	14	–	–	–	–	–	14
Weeding	–	–	–	–	–	–	–	20	–	10	–	–	30
Harvest	–	–	–	–	–	–	–	–	–	–	30	–	30
Total	0	0	0	0	0	0	14	20	0	10	30	0	74

[a] Other includes: drying, sales.

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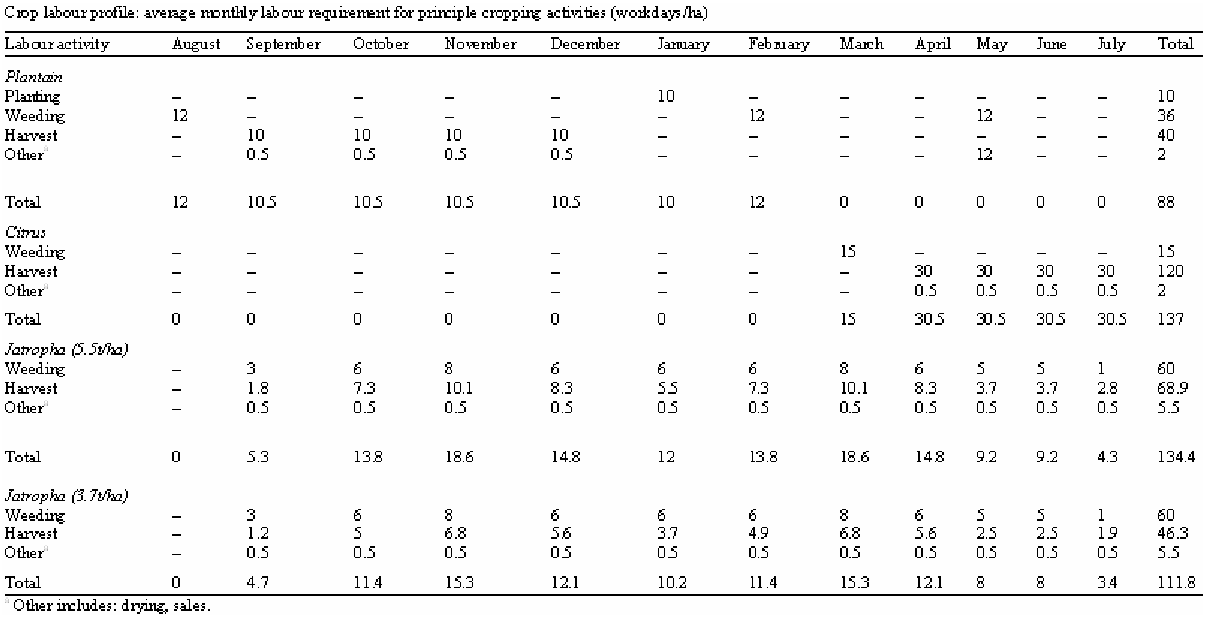
[100] This statement to me seems to be somewhat unrealistic as not every annual crop is cultivated during the whole year. In consideration of the deficient data set the 1:1 relation of annual crop cultivation and land preparation it is assumed to be an appropriate iteration.



Crop labour profile: average monthly labour requirement for principle cropping activities (workdays/ha)

Labour activity	August	September	October	November	December	January	February	March	April	May	June	July	Total
Plantain													
Planting	–	–	–	–	–	10	–	–	–	–	–	–	10
Weeding	12	–	–	–	–	–	12	–	–	12	–	–	36
Harvest	–	10	10	10	10	–	–	–	–	–	–	–	40
Other[a]	–	0.5	0.5	0.5	0.5	–	–	–	–	12	–	–	2
Total	12	10.5	10.5	10.5	10.5	10	12	0	0	0	0	0	88
Citrus													
Weeding	–	–	–	–	–	–	–	15	–	–	–	–	15
Harvest	–	–	–	–	–	–	–	–	30	30	30	30	120
Other[a]	–	–	–	–	–	–	–	–	0.5	0.5	0.5	0.5	2
Total	0	0	0	0	0	0	0	15	30.5	30.5	30.5	30.5	137
Jatropha (5.5t/ha)													
Weeding	–	3	6	8	6	6	6	8	6	5	5	1	60
Harvest	–	1.8	7.3	10.1	8.3	5.5	7.3	10.1	8.3	3.7	3.7	2.8	68.9
Other[a]	–	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	5.5
Total	0	5.3	13.8	18.6	14.8	12	13.8	18.6	14.8	9.2	9.2	4.3	134.4
Jatropha (3.7t/ha)													
Weeding	–	3	6	8	6	6	6	8	6	5	5	1	60
Harvest	–	1.2	5	6.8	5.6	3.7	4.9	6.8	5.6	2.5	2.5	1.9	46.3
Other[a]	–	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	5.5
Total	0	4.7	11.4	15.3	12.1	10.2	11.4	15.3	12.1	8	8	3.4	111.8

[a] Other includes: drying, sales.

Note: The yields of jatropha per hectare are calculated by determining the average yield over a period of 20 years, assuming the achievement of maximum yields of 6 and 4 t/ha, respectively, from the fourth year of cultivation onwards (see Appendix I (Table VII) for an overview of the yield development of jatropha. Accordingly, the labour demand for harvesting activities, which vary proportionally by yield (a field worker is assumed to pick 80 kg/day of jatropha seeds[101]), were adjusted on the basis of Appendix I (Table XII) that shows the labour requirements for the different cropping activities in the case of a yield of 6 tons per hectare.
Source: own illustration, following WHITE et al. (2005a), pp. 191 f.

Corresponding to the data given by the DED the calculated farm gate price for jatropha paid by local vegetable oil companies is US $180 per ton (Table 18). For the calculation of profits generated the 20 years` average[102] of the over time varying (increasing) revenues is employed. It is to be mentioned, that due to the fact that the DED project is still at an early stage of development (3rd year) – while jatropha is expected not to achieve its maximum yield between the 4th and 5th year – the information received is still not fully evident and should therefore be interpreted with caution. For that reason, yields as well as prices are varied within the different scenarios.

5.4.3.4 A Farm Household Agro-economic Optimization Model

In accordance with the economic theory applied (see Section 5.4.2) in this section a linear farm household model is designed in order to determine the profit-maximizing production plan. For this purpose the software GAMS (General Algebraic Modeling System) is employed. To assess whether the cultivation of jatropha is beneficiary to the farmers or not, a

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[101] This figure is based on harvest data in the Dominican Republic for 2,500 trees of jatropha per hectare (FLAMBERT (2006), p. 19).

[102] In correspondence with data achieved by the DED (SKODDOW et al. (2008)) a life expectancy of 20 years of the Jatropha tree is applied.

representative farm of 20 ha with three family members – man, woman, and child – is employed. The function to be maximised is the following:

$$(2) \qquad \pi = \sum_{i=1}^{n} p_i y_i - \sum_{j=1}^{m} w_j x_j - \sum_{k=1}^{p} C_{F_k} \overset{!}{=} \text{Max.}$$

whereby the first term stands for the aggregated revenues of all *n* crops (including annual and perennial crops) while the second one represents the sum of all input costs (j = 1, …, m). C_F denotes the aggregate fix costs over all p crops. The farm characteristics which simultaneously comply with the constraints are as follows: farm size, $H \leq 20$ ha; labour, $L \leq 63$ workdays per month; household subsistence production levels of annual crops; and non-negativity constraints for land and labour. Neither off-farm labour – as it only arises sporadically – nor the possibility of hiring labour is considered, since the farmers are poor with respect to financial resources (see Section 5.4.3.2). As land is an abundant factor, the rental costs are assumed to be zero.[103] The LP tableau can be seen in Table 20.

Table 20: Structure of the LP Model

Structure of the LP model

Row	Unit	Cropping systems (5)	Use Labour (12)	Use land (7)	Sell crops (5)	Direction	RHS
Objective function	US$	–	–	–	+		
Household Labour (12)	workday	+	–			<	63
Land (7)	ha	+		–1		<	20
Minima							
Rice (1)	kg	+				>	1000
Maize (1)	kg	+				>	500
Beans (1)	kg	+				>	100
Cassava (1)	kg	+				>	5000
Plantain (1)	bunches	+				>	350

Note: Figures in parentheses refer to the number of rows or columns in each category.
Source: own illustration, following WHITE et al. (2005a), p. 193.

The representative farm produces traditional crops, rice, maize, cassava, beans, citrus and plantain. All annual crops are integrated in a respective crop cycle of which each is in turn determined by a cropping system that produces for three years and is fallow for four years (see Table 21).

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[103] Even a ground rent above zero would be identical for all crops and all cases simulated by the model and would therefore not influence the ranking of the crop profitabilities generated by GAMS.

Table 21: Crops and Cycles of the Traditional Agricultural System and Jatropha

Crops and cycles of the traditional agricultural system and Jatropha
Crops and cycles
Rice-plantain-plantain
Maize-cassava-cassava
Beans-cassava-cassava
Citrus
Jatropha

Source: own illustration, following WHITE et al. (2005a), p. 193.

As bush fallow land management techniques are applied by the representative farm, modelling the entire scope of different crop production and fallow cycles over a multi-year period can be (computationally) demanding for various reasons. Due to former agricultural practices each of the land parcels created is resulting in an individual yield potential which analogously implies that land, in a similar manner to labour, cannot be regarded as a homogenous input to the production process. Additionally, potential problems can result first, with respect to coordinating the planting and harvesting times of each cropping cycle, and second, applying a proper discount rate over the analysis time horizon.

In order to reduce the computational complexity described above, a time-slice approach is employed. Hypothetically, for each cropping system the cultivated area is divided into seven land parcels, three representing the crop cycle and four the fallow periods. Using this method it is assumed that on each cultivated land parcel the whole cropping system is realized within one single year. Simultaneously, the approach implies that the loss of soil fertility occurring during the crop cycle is entirely recovered during the years of fallow. Hence, the quantity and agronomic characteristics of all land parcels in annual crops and fallow and thus, the intra-year labour use pattern is identical for any year (i. e., column). A stylized example of the time-slice approach is illustrated in Table 22.

Table 22: A stylized Crop Production-fallow Cycle of a Bush Fallow Farm Mosaic

A stylized crop production-fallow cycle of a bush fallow farm mosaic

Land parcel	Year						
	1	2	3	4	5	6	7
1	A1	A2	A3				
2		A1	A2	A3			
3			A1	A2	A3		
4				A1	A2	A3	
5					A1	A2	A3
6	A3					A1	A2
7	A2	A3					A1
8	P	P	P	P	P	P	P

A1, A2, A3, annual crop in year: 1, 2, 3, respectively; P, perennial crop.
Source: own illustration, following WHITE et al. (2005a), p. 194.

As the last simplifications crop prices are set fixed, and transaction costs such as transport costs are not taken into account. The fact, that the companies processing jatropha collect the seeds by themselves justifies the assumption made above, that transaction costs equal zero.

With the aid of the model constructed above besides (a) the base case two further alternative scenarios are simulated including (b) the additional cultivation of jatropha without changing the optimal production plan calculated for the base case, and (c) the optimization of the crop mix including the cultivation of jatropha by regarding the subsistence constraints. In the latter cases both, the price and the yield per hectare of jatropha are varied. Although the price for the ton of jatropha seeds is not unlikely to be above the expected US$ 180, as prices for crude oil as well as other vegetable oils than jatropha are continuing to increase[104], it is shown whether a more pessimistic appraisal, such as made by *Jatropha World – Center for Jatropha Promotion*[105], in the amount of US$ 140 would be able to change the results generated. Regarding the uncertainty accompanied with the relatively early phase of development of the above cited DED project with reference to the productivity of jatropha, three different yields per hectare, 4, 5 and 6 tons are considered.

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[104] At April the 14th, 2008, the crude oil price/barrel is US$ 109.65 (HANDELSBLATT (2008)). An overview about the development of the crude oil price/barrel during the past three years is given in Appendix I (Figure I).

[105] www.jatrophaworld.org.

5.4.4 Results[106]

5.4.4.1 Scenario a – Base Case

For the basic scenario the net farm income amounts approximately US$ 430. The profit-maximizing crop mix is calculated by using the aforementioned data, whereby the area occupied by citrus is fixed at 0.42 ha as stated by WHITE et al. (2005a). Due to a lack of information about the investment costs of extending the production of citrus in area, only a reduction is allowed. The rice-plantain system is cultivated on 0.5 ha and contributes 19 % of the net farm earnings. With respect to both fruits the area planted enables the farmers to produce exactly the subsistence level. Maize-cassava occupies 0.25 ha and generates 29 % of the farm profits. This again allows for precisely the respective subsistence production. As beans is the most profitable crop besides citrus, as the only cropping system the beans-cassava system is extended until the labour limit is reached in August. It conduces 27 % of the net farm income. The shadow price for August is valued at US$ 11.40. The significant deviation from the results generated by WHITE et al. (2005a) is either the consequence of partially inconsistent data – as already described above – or caused by erroneous calculations. The total area cultivated is 3.3 ha, of which 2.88 ha is planted with annual crops, and 0.42 ha with perennials. Another 2.88 ha is fallow land in preparation. The results of the base case are tabulated and contrasted to the results of scenario (b) and (c) in Table 23.

5.4.4.2 Scenario b – Additional Cultivation

It could be shown that the additional cultivation of jatropha would be beneficiary to the farmers, as its labour requirement is complementary to the demand of traditional crops. In the best-case scenario, assuming a price of US$ 180 for the ton of jatropha seeds and an average yield of 5.5 tons per hectare, jatropha is cultivated on an area of 0.48 ha, which leads to an increase in net farm income of 130 to US$ 560. Its share of the net earnings is about 23 %. Up to the third subcase, which presumes a yield of 3.7 tons per hectare at a price of US$ 180, the cultivation of jatropha stays reasonable. In subcase 3 the net farm earnings still rise slightly by 22 US$, to which jatropha contributes around 5 % compared to the base scenario. It is striking that the area occupied by jatropha from subcase 2 to subcase 3 is expanded from 0.48 to 0.61 ha. This is due to the lower labour demand per hectare. Although the area is widened by approximately 20 %, both, the contribution to total farm profits as well as the profit itself de-

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[106] For an overview of all codes programmed with GAMS for all scenarios and subcases considered in the following, see Appendix II (Codes I – IX).

crease just slightly by 0.4 %. As the absolute production levels of the traditional crops were fixed ex-ante, their relative shares decline by a factor corresponding to the contribution of jatropha to the total farm earnings.

Only in the worst-case scenario with a price of US$ 140 and a representative yield of 3.7 tons per hectare jatropha is not a viable option anymore, and thus, not cultivated. As the production areas of traditional crops were fixed for calculation, the optimal crop mix is exactly the same as in the base scenario.

The shadow price for labour in July, when the labour peak occurs, is extremely high for sub-scenario 1 at US$ 66.90. Worsening the assumptions in sub-case 2 it is only 15.70, and 14.70 US$ in sub-case 3 and in the last subcase it equals the standard wage rate for family labour in the amount of 4 US$. This means, that in the first three subcases in July it would be lucrative to the farmers to hire additional labour force, as far as off-farm labour was available, whereas in subcase 4 the farmers would not increase their production, since the labour shadow price is below the price for hired labour. On the other hand, neglecting the assumptions made for scenario b – fix production levels of all other crops except jatropha corresponding to the base case –, the solution is identical to the one of the base scenario, revealing the effective shadow price for labour in August (see above), that equals the value of 11.40 US$. As in this scenario (b) the extent to which jatropha is cultivated is the only variable, one can at least say that the value of labour by tendency rises and falls, respectively, with the profitability of jatropha, measured on a per hectare basis, but as the particular optimal production levels are highly interdependent, it would be precarious to conclude a definite correlation between the profitability of jatropha and the labour shadow price.

5.4.4.3 Scenario c – Profit Maximization

In the last scenario only the production of annual crops is fixed corresponding to the respective subsistence requirements. As citrus is not needed to maintain subsistence, its production level is only bounded upwards, for the aforementioned reasons (see Section 5.4.4.1 – scenario a). In the optimal solutions of subcases 1 and 2 jatropha is cultivated on an area of 2.4 ha, while citrus is slightly displaced by jatropha. The reduction of the area covered with citrus is reduced by 0.01 ha. The net farm earnings rise by a much greater extent than in scenario b. In the first sub-scenario they even reach the value of US$ 1016 of which jatropha generates 64

%. Like in scenario b, the cultivation of jatropha stays beneficial until the third sub-case, in which the total profit still rises by US$ 45 with regards to the base-case and the share of jatropha of the net farm income is around 22 %.

In sub-case 3 jatropha is cultivated on an area of 2.89 and citrus on 0.42 ha. Regarding sub-case 2, this means a rise in both areas, whereas the total farm profits gently decrease by approximately 11 US$ or 1.9 %. By cultivating jatropha it is possible to alleviate labour scarcity and therefore, to achieve a higher net income. Generally, citrus would also enable the farmers to do so, as it is cultivated in months others than August, when land is to be prepared and in the base case the labour peak is reached. Although the crop offers a higher profit per hectare, jatropha is more profitable in terms of labour demand due to the fact, that the labour requirement for citrus cultivation is highly concentrated in specific months, while jatropha shows a much more modest and balanced labour requirement throughout the year (see Table 19). For this reason, jatropha can be planted on a larger area.[107] While in the first two sub-scenarios the area covered by annual crops stays constantly at the levels of the base-case, it is expanded (hier in subcase 3) insignificantly in the case of the beans-cassava cycle.

Analogous to scenario b in sub-case 4 the cultivation of jatropha is not economically reasonable anymore. Again the optimal crop mix matches the results of the base scenario.

The shadow prices for labour resulting from scenario c for the first three sub-cases are in general lower than the prices calculated for the previous scenario. This reflects the changes in the assumptions made. As the production levels are less restricted in scenario c, the production capacities are exhausted more efficiently compared to scenario b. For the same reason, the calculated labour shadow prices are far closer to the given regional standard wage rate. In the first two sub-cases labour shadow prices exist for July and November. The one for July stays constantly at US$ 12.60 in both sub-scenarios, as they are mainly determined by the crops more profitable in terms of profit per workday. For that reason, the shadow price for labour does not change, although the price for jatropha seeds falls by nearly one quarter. This was proven by lifting the labour limit in July by one workday to 64 days per month. It could be seen, that the level of production did not increase, but rather decrease. Obviously, the main determinants for the labour shadow price are citrus as well as cassava (and beans, due to the

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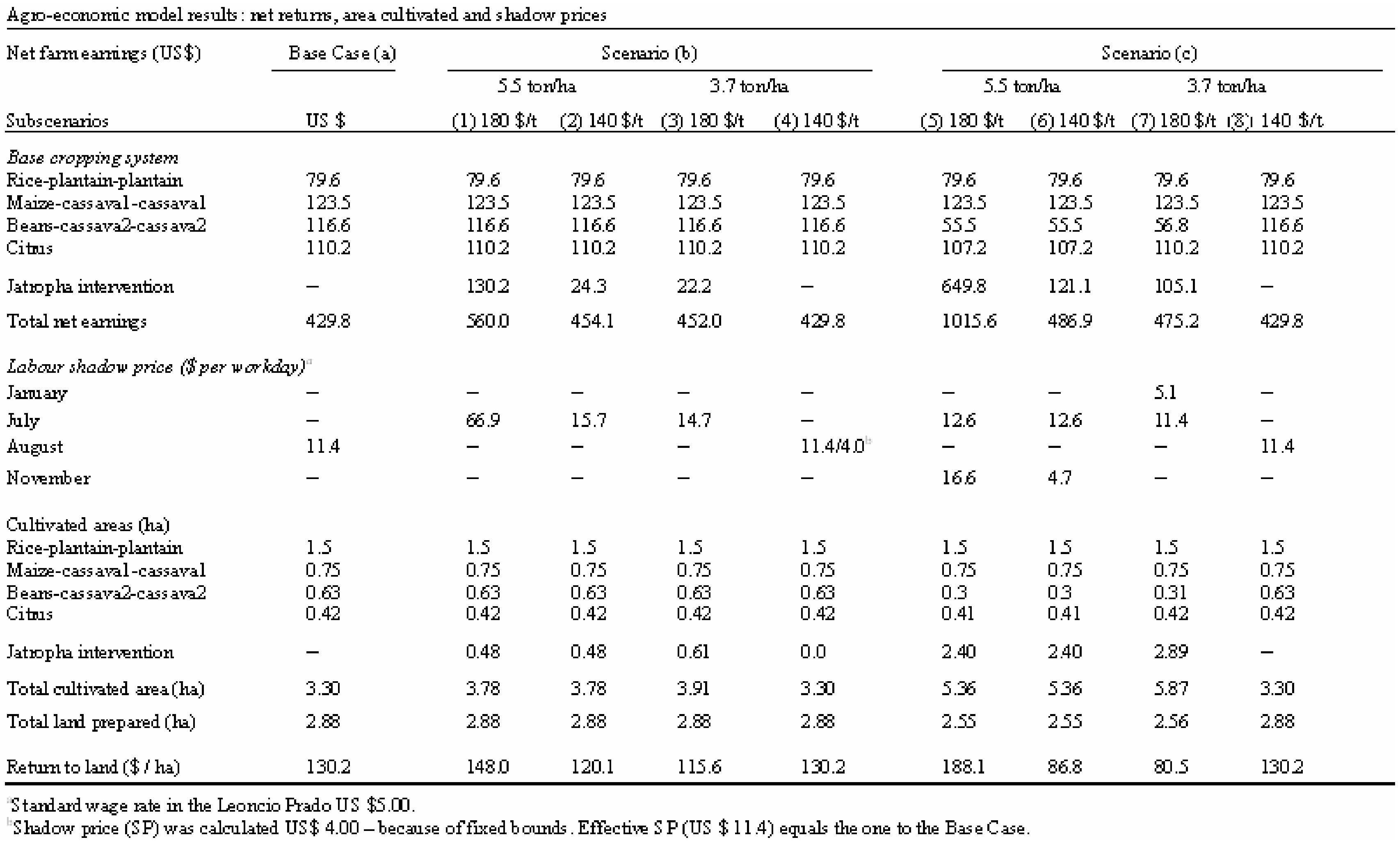
[107] Even neglecting the side condition with respect to citrus (i. e. without applying the upper bound for citrus cultivation of 0.42 ha.), its production is only increased marginally, while Jatropha is also increased slightly compared to the case, in which the restriction is considered.

cycle constraint). By contrast, in the aforementioned modification of sub-case 1 and 2 the production levels of these crops were increased. Analogously, the decline of the shadow price for labour in November from US$ 16.60 in sub-case 1 to US$ 4.70 in sub-case 2 underlines the strong impact outgoing from the change in profitability of jatropha, since its labour demand is relatively intensive in that month. In compliance with the modification made (see above) this result has been verified. In other words, in sub-case 1 in November (as well as in July, but less) it would profit the farmers to employ temporary labour, if it was available, whereby jatropha would generate the largest share of the additional net income, whereas in sub-case 2 hiring temporary labour would not pay off, as the standard wage rate is above the computed shadow price of 4.70 US$.

In sub-case 3 there are labour shadow prices for January and July, which value at 5.1 and 11.40 US$, respectively. Following the above explanations, the shadow price for July drops slightly mainly due to the higher labour resource consumption as a consequence of the extended production of citrus and the beans-cassava system. In January the labour shadow price values at US$ 5.10. Hence, hiring temporary labour would pay off in January, as the shadow price is above US$ 5. Rising the amount of labour available by one workday, jatropha production is increased slightly, and an extra profit of US$ 0.35 is obtained.

The results of sub-case 4 – the worst-case scenario – again reflect the results of the base case. jatropha is not profitable anymore and therefore, not cultivated. All results are summarised in Table 23.

Table 23: Agro-economic Model Results: Net Returns and Area cultivated



Agro-economic model results : net returns, area cultivated and shadow prices

Net farm earnings (US$)	Base Case (a)	Scenario (b)				Scenario (c)			
		5.5 ton/ha		3.7 ton/ha		5.5 ton/ha		3.7 ton/ha	
Subscenarios	US $	(1) 180 $/t	(2) 140 $/t	(3) 180 $/t	(4) 140 $/t	(5) 180 $/t	(6) 140 $/t	(7) 180 $/t	(8) 140 $/t
Base cropping system									
Rice-plantain-plantain	79.6	79.6	79.6	79.6	79.6	79.6	79.6	79.6	79.6
Maize-cassava1-cassava1	123.5	123.5	123.5	123.5	123.5	123.5	123.5	123.5	123.5
Beans-cassava2-cassava2	116.6	116.6	116.6	116.6	116.6	55.5	55.5	56.8	116.6
Citrus	110.2	110.2	110.2	110.2	110.2	107.2	107.2	110.2	110.2
Jatropha intervention	–	130.2	24.3	22.2	–	649.8	121.1	105.1	–
Total net earnings	429.8	560.0	454.1	452.0	429.8	1015.6	486.9	475.2	429.8
Labour shadow price ($ per workday)[a]									
January	–	–	–	–	–	–	–	5.1	–
July	–	66.9	15.7	14.7	–	12.6	12.6	11.4	–
August	11.4	–	–	–	11.4/4.0[b]	–	–	–	11.4
November	–	–	–	–	–	16.6	4.7	–	–
Cultivated areas (ha)									
Rice-plantain-plantain	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Maize-cassava1-cassava1	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Beans-cassava2-cassava2	0.63	0.63	0.63	0.63	0.63	0.3	0.3	0.31	0.63
Citrus	0.42	0.42	0.42	0.42	0.42	0.41	0.41	0.42	0.42
Jatropha intervention	–	0.48	0.48	0.61	0.0	2.40	2.40	2.89	–
Total cultivated area (ha)	3.30	3.78	3.78	3.91	3.30	5.36	5.36	5.87	3.30
Total land prepared (ha)	2.88	2.88	2.88	2.88	2.88	2.55	2.55	2.56	2.88
Return to land ($ / ha)	130.2	148.0	120.1	115.6	130.2	188.1	86.8	80.5	130.2

[a] Standard wage rate in the Leoncio Prado US $5.00.

[b] Shadow price (SP) was calculated US$ 4.00 – because of fixed bounds. Effective SP (US $ 11.4) equals the one to the Base Case.

5.4.5 Conclusions

By means of the model constructed it could be shown that the cultivation of jatropha could be economically reasonable, except in the worst case of relatively pessimistic assumptions with respect to prices and yields. In terms of sustainability it is to be awaited, how the variables will develop in the future. While against the background of an upwards price trend for crude oil the price of jatropha is unlikely to fall, yields as well as production costs are linked with a high degree of uncertainty. As reported from projects in other countries (e.g. India), fertilizer use could enhance outputs substantially (OUWENS et al. (2007)). Reversely, one could possibly assume a decline in yields as probable. Considering the financial situation of the farmers subject to this study, fertilizer use is not likely to be applied by them. In this context further research should be aiming at the re-use of the seedcake as manure. A supposable alternative could be the re-buy of the seedcake from the oil processing companies for a relatively small reduction of the price received. Besides yields and prices, other factors affecting the profitability of jatropha, such as pests, diseases, or unexpectedly high labour requirements, which cannot be precisely predicted, as the respective research is still in its infancy. According to SKODDOW et al. (2008), the same as for fertilizers is expected to apply for pesticides, as well, but no hard data is available, yet. The data used are largely based on estimations. For that reason, fertilizer and pesticide costs are not considered in the framework of this analysis, as they were on the one hand eligible to reduce the profitability of the plant, but – on the other hand – simultaneously capable of increasing yields considerably. With regards to/As regards the labour demand, jatropha has – like other perennial crops, too – the great advantage, that no land preparation (except during the first time of plantation) is required, an important fact considering the prevailing labour scarcity and the great impact of labour costs to agricultural production.

Leaving the microeconomic perspective, provided that the future development of the variables will not match the worst-case scenario, the cultivation of jatropha is likely to be an opportunity not only to improve the economic situation, but also to contribute to rural development, e. g. the improvement of the local energy supply or the (local) infrastructure. The fact, that (private) companies are directly involved into the value chain, could accelerate the development process, since they have an own interest in upgrading the distribution channels.

While the economic potential is assessed to be existent, the main risks are of an ecological as well as a social nature. On the one hand, the replacement of conventional diesel by jatropha oil helps to reduce CO_2-emissions, but on the other hand, there are other factors already discussed (see Section 5.3.2) affecting the energy- and GHG-balance as well as the environment. The most problematic case would be the displacement of tropical rainforest. In order to be able to benefit from the entire ecologic potential of the crop, the government ought to ensure, that the tree is only planted on deforested and degraded land. The risks accompanied by intensive agricultural practices in this case can be neglected, as they are very unlikely to be adapted by the target group.

The second main risk concerns the national food security, which would be further deteriorated as it already is at present (see Section 5.1.2). By looking at the results of scenario c one can already figure out, that the crops, whose production levels stay at the respective subsistence levels will be the crops displaced, namely the rice-plantain as well as the maize-cassava cycle. This assumption can be proven by putting aside the subsistence restrictions. In the first three sub-cases which – in this regard – are decisive, the net income raises at the cost of the displacement of basic food crops. Only the beans-cassava cycle is further produced in all sub-scenarios, since beans are very lucrative to cultivate.

6 Summary and Outlook

Even though fossil energy carriers are expected to remain the predominant energy source at least until 2030 (IEA (2006b), p. 2, IPCC (2007), p. 272), in the last decade economic, ecological, and political interest in biomass as a source of renewable energy has become more and more intense around the world, as it is potentially capable of contributing to the mitigation of climate change as well as the improvement of energy security and rural development. During the past decade this has been reflected by continuously growing production figures accompanied by remarkably increasing investment flows and biofuel policies promoting renewable energy carriers including biofuels, such as legally binding targets. Independent projections agree upon the fact, that within the next decades the biofuels sector will continue to expand rapidly, but come to highly varying conclusions as regards the estimates of absolute numbers. Nevertheless, it is compulsory looking into this subject, as biofuels as one option of a wider portfolio of renewable energy sources (DE LA TORRE UGARTE (2006)) are not only potentially beneficial but also holding uncertainties regarding eventually negative impacts on both, environment and society.

Crucial indicators to assess environmental impacts of biomass production are the energy and GHG balances as well as ecosystem impacts. Thereby, the most severe consequences are expected to arise from land-use changes, in the worst case the conversion of natural forest into an intensive cultivation of bioenergy crops, having been observed in various countries such as Malaysia, Brazil, and Indonesia. In these cases the overall life-cycle balance is likely not only to diminish but to even turn negative. In general it can be said, that benefits are assumed to occur most probably in case of an extensive and diverse cultivation either replacing an intensive one, or being implemented on land which is undergoing uncontrolled degradation (KARTHA (2006), p. 2, SRU (2007), p. 49). According to the aforementioned arguments, the actual contribution of a particular biomass path to climate change mitigation is to be questioned unless a precise and comprehensive life-cycle assessment is performed ("well to wheel" approach), proving either predominantly positive or predominantly negative ecological effects (SRU (2007), p.39). In the framework of each analysis of bioenergy production systems the specific local conditions need to taken into account in order to avoid generating environmental problems (KARTHA (2006), p. 2).

Another sensitive issue linked to the cultivation of biomass is the assurance of food security, as the cultivation of biomass feedstock is becoming more attractive due to steadily rising energy prices and therefore, displacing food production. This leads first, to a shortage of food supply and second, to increasing food prices affecting most the poor sections of the population already having an insecure access to food. Therefore, a shift from food to bioenergy crop production is to be avoided, since food security is a basic human need which should not be compromised by bioenergy development. Also a problem especially affecting the populations of developing countries refers to labour conditions and land rights. As most of ambitious biofuel targets around the globe cannot be met by own produces (e.g. Europe), increasing export volumes from developing countries not corresponding to a sustainable production scheme in terms of this study are expected (SRU (2007), p. 85). Therefore, in order to avoid or at least to minimise possible negative impacts and rather to promote the potential benefits, the entire supply system for bioenergy – from feedstock cultivation right up to its respective downstream processing – international trade should be forced to comply with respective ILO standards that set out rules sustainable bioenergy development should abide by (FRITSCHE et al. (2006), pp. 9, 20 f.). In case the whole production chain is managed adequately, synergy effects leading to significant benefits can be achieved between the production of biomass for bioenergy on the one side and climate and environmental protection as well as social and economic development on the other side (SRU (2007), p. 49). "In either case, providing social benefits will require engaging local communities and understanding the current uses of the land, such as food production, livestock grazing, and fuel wood gathering. Bioenergy crop production can be a suitable alternative to fossil fuels, if it is designed in a participatory manner with those whose livelihoods will be affected" (KARTHA (2006), p. 2). Regrettably, no certification scheme exists, yet, covering all aspects of sustainability. Moreover, since all existing certification schemes are of a voluntary nature the enforcement of necessary standards cannot be assured (SRU (2007), p. 102).

Peru has made some initial steps towards the development of a sustainable biofuel industry. Within actions taken, a basic legal framework as well as fuel blending targets of 7.8 % by 2010 for ethanol as well as 2 % by 2009 and 5 % by 2011, respectively for biodiesel were set and also environmental concerns are being addressed (ROTKOPF (2007), p. 102). Peru's agriculture is attending with some very good preconditions for the production of both, ethanol as well as biodiesel. Especially the sugar cane industry as it has the highest yields in the world is very promising to promote ethanol production. However, at present the production of biofuels is still in an experimental stage with low production rates for ethanol and almost no production of biodiesel. Consequently, it seems rather impossible at the moment to fulfil the mandatory fuel blending targets mentioned above. Nevertheless, there is a huge interest of national and foreign investors to promote the biofuels industry. Many promising investment projects are already in process or at least announced.

As for jatropha, by means of an LP model it could be shown that in the region of San Martín, Peru the cultivation can generally be considered to be viable in economic terms. Thereby, it could help farmers to improve their situation in regards to income generation and rural development. Nonetheless, uncertainties continue to exist with respect to environmental and social externalities. The model confirmed assumptions about possibly resulting food shortages, as less profitable food crops c. p. would be replaced. If food security is to be maintained, any further incentives should be set up by politicians to ensure the current level of food supply and not to shift from food to jatropha production (ACHTEN et al. (2007), p. 288, JONGSCHAAP et al. (2007), p. 23).

The energy and GHG balances, on the other hand, are expected to be positive, but significantly dependant first, on the type of land used for cultivation – marginal land, wasteland, or natural forest – and second, on the type of cultivation, particularly its intensity. In case of converting wastelands effects seem to be acceptable or even positive, whereas converting natural forest would be accompanied by undesirable consequences (FRANCIS et al. (2005), p. 22). The impacts on soils, biodiversity, and on water balances are partly uncertain. Generally, jatropha is regarded to be capable of sustaining or even reclaiming soil fertility as well as enriching biodiversity. In the case of Peru this is an important factor to consider, as the Peruvian Amazon region counts with 3,000,000 ha of deforested land, which could be used without provoking further severe land-use changes. Presuming an average yield of 6 tons of seeds per hectare, on average containing 33 % of vegetable oil, by cultivating only two thirds of this area Peru`s total demand for diesel could henceforth theoretically be replaced by jatropha-based biodiesel. At least by only cultivating 5 % of the deforested area, the blending targets by 2011 for biodiesel could be fulfilled (see Appendix I (Table XIII)). Not least from this point of view – put the case that all potential benefits and risks have been carefully considered – jatropha is to be an option worth fostering. On the other hand, as long as uncertainties still remain, small scale farmers should not invest. There is still an urgent need for further research with respect to seed yields, yield responsiveness to inputs, land-use impacts, and the systematic selection of the best suitable genetic material (ACHTEN et al. (2007), p. 289). Besides, further necessary investigation refers to health risks due to toxic elements of jatropha.

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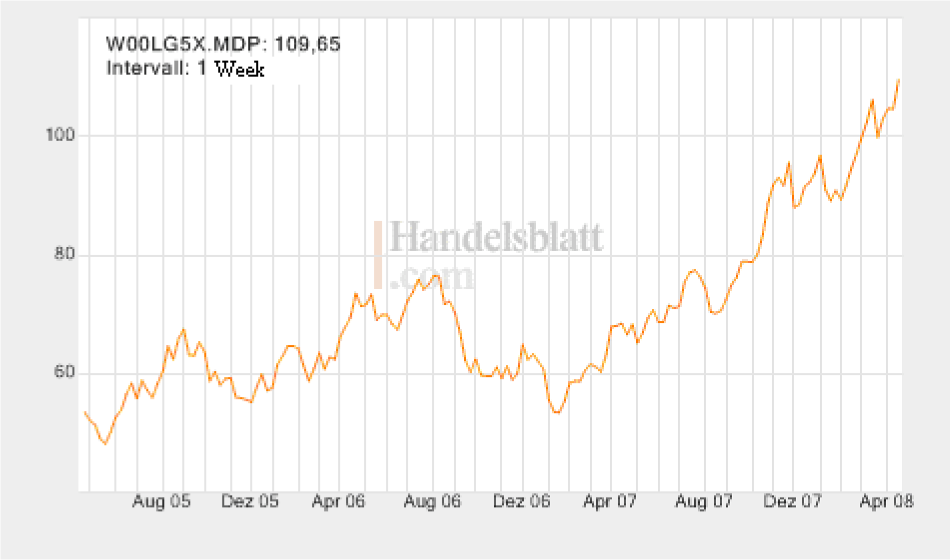
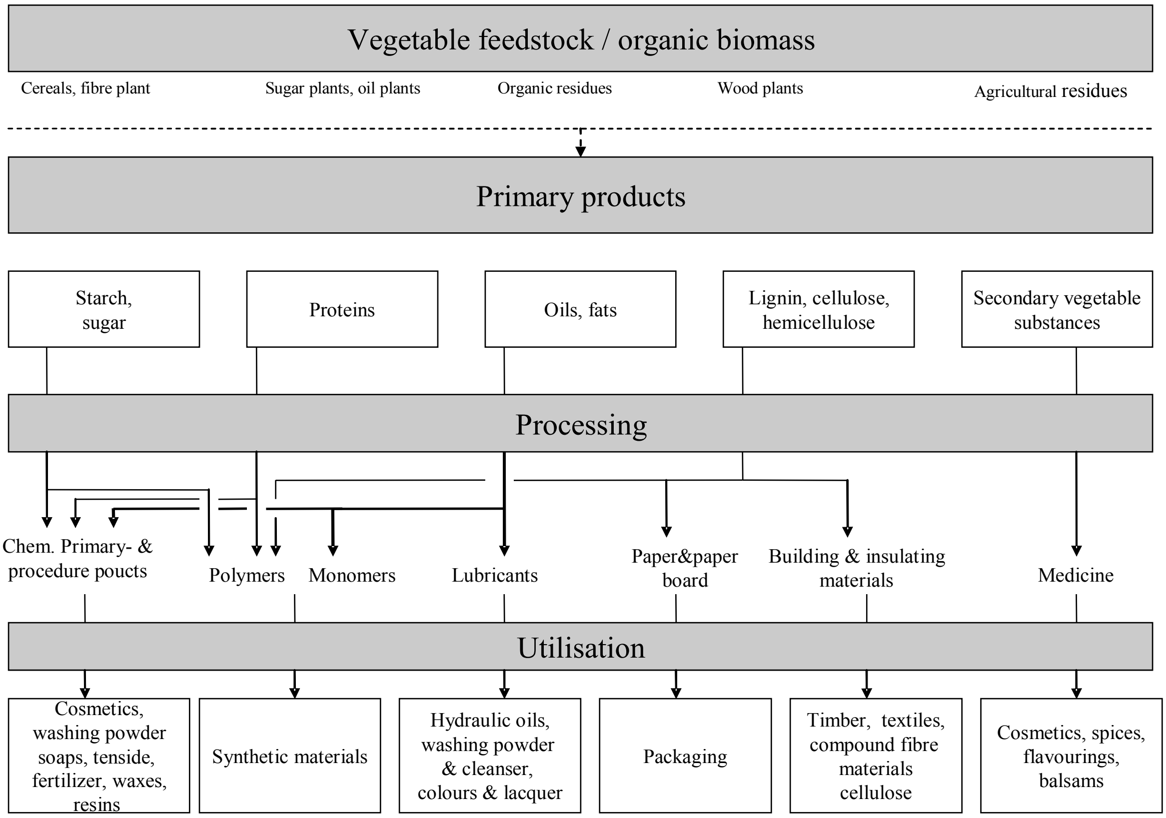
Appendix I

Figure I: Development of the crude oil price per barrel, 2005 – 2008



Source: HANDELSBLATT (2008)

Figure II: Overview of the materials use life cycle



Source: SRU (2007), p. 11.

Figure III: Labour requirements (total and subsistence production activities) of a typical bush fallow farm and monthly

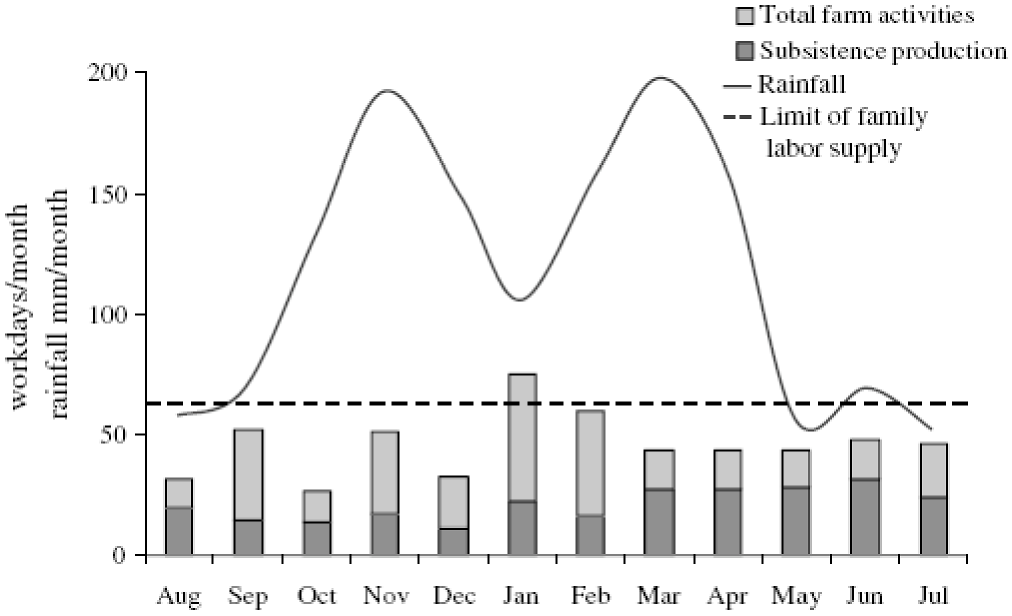


Fig. 1. Labor requirements (total and subsistence production activities) of a typical bush fallow farm and monthly rainfall.

Source: WHITE et al (2005a), p. 188.

Table IV: Overview of different types and technologies to generate biofuels (1st generation)

Overview of different types and technologies to generate biofuels (1st generation)

Biofuel type	**Specific Name**	**Biomass feedstock**	**Production Process**
Bioethanol	Conventional bioethanol	Sugar beets, grains	Hydrolysis and fermentation
Pure vegetable oil	Pure plant oil (PPO) (e.g. jatropha)	Oil crops extraction	Cold pressing/
Biodiesel	Biodiesel from energy crops Rape seed methyl ester (RME) Fatty acid methyl/ ethyl ester (FAME/FAEE)	Oil crops (e.g. jatropha)	Cold pressing/ extraction and transesterification
Biodiesel	Biodiesel from waste FAME/FAEE	Waste/cooking/frying oil	Transesterification
Biogas	Upgraded Biogas	(Wet) biomass	Digestion
Bio-ETBE[108]			Chemical synthesis

Source: Own illustration, following BIOFUELS RESEARCH ADVISORY COUNCIL (2006), p. 11.

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[108] ethyl tertiary butyl ether (ETBE) (etherification of ethanol and isobutene, a by-product of refinery processes)

Table V: Summary of current production, future targets and policies in various countries

Biofuel	Current capacity	Future targets - quantity and year	Main sources for biofuel	Biofuel policies (explicit)	Main trade policies for biofuels
US	18.4 billion litres of ethanol (2006), 284 million litres biodiesel (2005)	28 billion litres of ethanol by 2012 and 1 billion litres of cellulosic ethanol by 2013	maize and in future cellulosic sources	excise tax credit, mandatory blending, capital grants, vehicle subsidies	import tariff of $0.1427 per litre ethanol plus advalorem tariff with some exemption for carribbean countries
Brazil	17.5 billion litres (2006)	25 % blending of ethanol (has been in effect for long time), 2.4 bill. litres of biodiesel by 2013	sugar cane, soybean	mandatory blending, capital subsidies, vehicle subsidies	20 % advalorem import tariff on ethanol (waived in case of domestic shortage
EU	3.6 billion litres of biodiesel (2005), 1.6 billion litres of ethanol (2006)	5.75 percent of transportation fuel on energy basis by 2010	rapeseed, sunflower, wheat, sugar beet and barley	excise tax credit (beginning to be phased out), carbon tax credit, mandatory blending, capital grants and funding for R&D	ad valorem duty of 6.5 % on biodiesel and import tariff of $0.26 per litre on ethanol (latter is waived for some categories countries)
China	1.2 billion litres of ethanol (2006)	*na**	maize, cassava, sugar cane	subsidies and tax breaks but only for non-grain feedstock	import tariff of 30 % on ethanol
Colombia	400 million litres of ethanol (2006)	10 percent ethanol blending in cities exceed 500,000 people since 2006	sugar cane, oil palm	mandatory blending, tax breaks for sugar cane plantations, capital subsidies	ad valorem import tariff of 15 % on ethanol and 10 % on biodiesel
Indonesia	340 million litres of biodiesel (2006)	10 % ethanol and 10 % biodiesel effective April 2006	oil palm	mandatory blending, capital subsidies	lower export tax for processed oils compared to crude palm oil
Malaysia	340 million litres of biodiesel (2006)	5 % biodiesel from April 2007	oil palm	mandatory blending, capital subsidies	lower export tax for processed oils compared to crude palm oil
Thailand	330 million litres of ethanol(2006)	*Na*	cassava, sugar cane molasses	price subsidy, capital subsidies,	import tariff of 2.5 baht per litre and ad valorem tariff of 5 % on biodiesel
Canada	240 million litres of ethanol (2006)	5 % ethanol by 2010 and 2 % biodiesel by 2012	maize and wheat	mandatory blending, excise tax credit, capital subsidies	import tariff of $0.1228 for ethanol and $0.11 for biodiesel
Argentina	204 million litres of ethanol (2006)	5 % biofuel by 2010	soybean	excise tax credit, mandatory blending, export tax exemption on biofuel blends	low export tax (5 %) for soy biodiesel compared to soy beans (23.5 %) and soy oil (20 %)
India	200 million litres of ethanol (2006)	5 % ethanol in select cities and 10 % biodiesel by 2012**	sugar cane molasses, jatropha (in future)	mandatory blending for ethanol, capital subsidies	advalorem duty of 199 % on CIF value of denatured ethanol and 59 % duty on undenatured ethanol
Australia	170 million litres of ethanol	350 million litres of biofuel by 2010	wheat and molasses	producer subsidy, capital grants, vehicle standard	import tariff of $0.31 per litre on both ethanol and biodiesel
Japan	insignificant	360 million litres by 2010 and 10 % biofuel by 2030	imported ethanol	excise tax credit	ad valorem import duty of 23.8 % on fuel ethanol (to be lowered to 10% by 2010)
Peru	Around 30 million litres of ethanol	2 and 5 % of biodiesel in 2009 and 2011; 7.8 % of ethanol by 2010	Sugar cane	Mandatory blending	
Dominican Rep.	Insignificant	15 % ethanol and 2 % biodiesel by 2015	Sugar cane	Mandatory blending	
Philippines	insignificant	1 % biodiesel, 5 % ethanol by 2008; 2 % biodiesel, 10 % ethanol by 2011	Sugar cane, cassava, yam, sweet potatoe	Mandatory blending	
Bolivia	insignificant	2..5 % and 20 % biodiesel by 2007 and 2015	Sugar cane	Mandatory blending	

* data not found

** biodiesel policy has not yet passed into law in India and is merely a government preference at this point. Note: agricultural policies that affect production of biofuel crops is not covered here

Source: RAJAGOPAL et al. (2007), p. 106, REN21 (2008), p. 39.

Table VI Production Costs for bioethanol and biodiesel for selected countries

Country / feedstock	Cost / litre (US$)
Bioethanol	
EU (wheat/beet)	0,51-0,80
Brazil (sugar cane, 2005)	0,25
US (maize)	0,40 – 0,50
Australia (sugar cane 2005)	0,38
Thailand (sugar cane 2005)	0,27
China (sugar cane 2005)	0,53
Biodiesel	
EU (rapeseed, 2002)	0,40 – 0,80
US (soya, 2002)	0,40 – 0,67
India (jatropha, 2005)	0,40 – 0,53

Source: DUFEY et al. (2007a), p. 19.

Table VII: Final energy consumption according to sources (in TJ)

Source	2006
Mineral Coal	15 336
Wood	74 496
Pomace & Yareta	10 243
Bagasse	8 955
Solar Energy	2 337
Coke	1 325
Charcoal	2 255
Liquid Gas	34 241
Motor Petrol	39 522
Kerosene	23 816
Diesel Oil	127 903
Industrial Petrol	45 243
Non energetics of Petrol and Gas	9 025
Distributed Gas	13 974
Industrial Gas	1 678
Electricity	87 774
Total	**498 121**

Source: MEM, (2006), p. 18.

Table VIII: Summary of Announced Ethanol Production Projects

Project	Region	Crop	Area on average (ha)	Average investment (US$)	Initial Year	Estimated Production (,000 tons/year)
Maple Etanol	Piura (valle del Chira)	Sugar cane	12 000 (new ones)	32 mill. in 5 years, 100 mill. more expected	2008	120-150 (350 a los 5 años)
Caña Brava (Grupo Romero	Piura (valle del Chira)	Sugar cane	3 300 (new ones)	40 mill.	2010	54
COMISA	Piura (Sullana)	Sugar cane	12 000 (new ones)	81 mill.	*n.a.	180
Empresa Agrícola Chira	Piura (Amotape)	Sugar cane	96 (new ones)	100 mill.	2006	*n.a.
Various	Piura (valle del Chira	Sugar cane	500 (new ones)	*n.a.	*n.a.	*n.a.
Cayaltí y Bioterra	Lambayeque	Sugar cane	12 000 (only 6500 new ones)	90-100 mill.	*n.a.	60
Tumán	Lambayeque	Sweet Sorghum	300 (new ones)	*n.a.	*n.a.	*n.a.
Pomalca (Dedini)	Lambayeque	Sugar cane	10 000 (existent)	*n.a.	*n.a.	*n.a.
Casa Grande-Cartavio (Grupo Gloria)	La Libertad	Sugar cane	40 000 (existent)	30 mill.	2007	320 + 15
Arena Dulce (Grupo Manuelita)	La Libertad (Chavimochic)	Sugar cane	4000 – 7000 (3700-6700 new ones)	*n.a.	*n.a.	*n.a.
San Jacinto	Ancash	Sugar cane	*n.a.	30 mill.	*n.a.	36
Andahuasi	Lima (Huaura)	Sugar cane		10 mill.	2010	*n.a.
Palma Selva S.A.	San Martín	Sugar cane	2000	*n.a.	*n.a.	*n.a.
Shanao	San Martín (Lamas)	*n.a.	*n.a.	*n.a.	*n.a.	*n.a.
Ciavasa	Ucayali	Sugar cane	50 000	50 mill.	2010	47
EDUSAC	Ucayali	Sugar cane	60 000	120 mill.	*n.a.	*n.a.
Andahuasi	San Martín (Cainarachi	Sugar cane	10 000 (new ones)	19 mill.	*n.a.	36
Calzada Etanol	San Martín	Sugar cane	500	*n.a.	*n.a.	*n.a.
Asoiación Agrícola Agua Blanca	Ucayali	Sugar cane	50	100 mill.	*n.a.	*n.a.
Agroforestal Campo Verde	Ucayali	Sugar cane	80	160 mill.	*n.a.	*n.a.
Total with information			**164 026 (new areas)**	**661,36 millions**		**1098**

Source: CASTRO et al (2008), pp. 77 f.

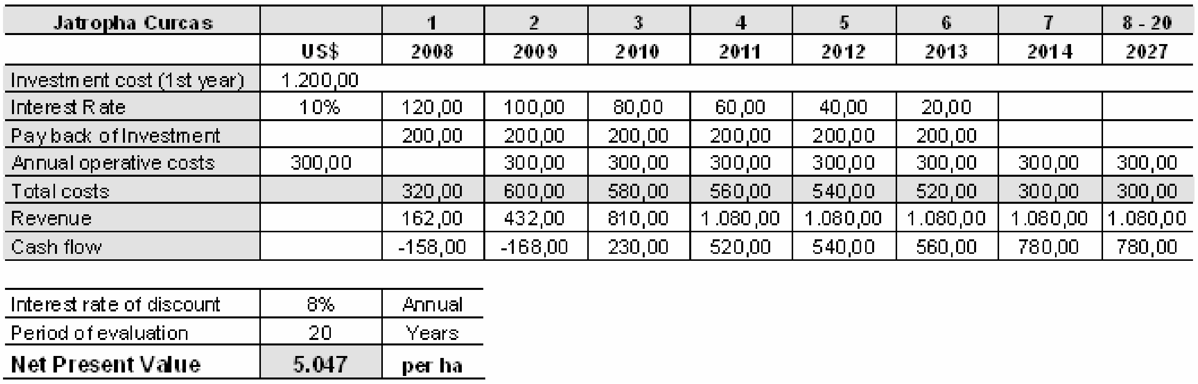
Table IX: Characteristics of Jatropha biodiesel compared to European specifications

Characteristic	Jatropha biodiesel	European Standard	Remarks
Density (g cm³ at 20°C)	0.87	0.860-0.900	+
Flash point (°C)	191	>101	+
Cetane no. (ISO 5165)	57-62	>51	+++
Viscosity (mm²/s at 40°C)	4.20	3.5-5 (40°C)	+
Net. Cal. Val. (MJ/L)	34.4 (or 39.5 MJ/g)	-	-
Iodine No.	95-106	<120	+
Sulphated ash	0.014	<0.02	+
Carbon residue	0.025	<0.3	++

Note: + indicates that jatropha performs better than the European standard for diesel

Source: FRANCIS et al. (2005), p. 18.

Table X: CBA - Calculation for the Small Farmer



Jatropha Curcas		1	2	3	4	5	6	7	8 - 20
	US$	2008	2009	2010	2011	2012	2013	2014	2027
Investment cost (1st year)	1.200,00								
Interest Rate	10%	120,00	100,00	80,00	60,00	40,00	20,00		
Pay back of Investment		200,00	200,00	200,00	200,00	200,00	200,00		
Annual operative costs	300,00		300,00	300,00	300,00	300,00	300,00	300,00	300,00
Total costs		320,00	600,00	580,00	560,00	540,00	520,00	300,00	300,00
Revenue		162,00	432,00	810,00	1.080,00	1.080,00	1.080,00	1.080,00	1.080,00
Cash flow		-158,00	-168,00	230,00	520,00	540,00	560,00	780,00	780,00

Interest rate of discount	8%	Annual
Period of evaluation	20	Years
Net Present Value	**5.047**	**per ha**

Source: Own calculation based on figures received by the DED (2008).

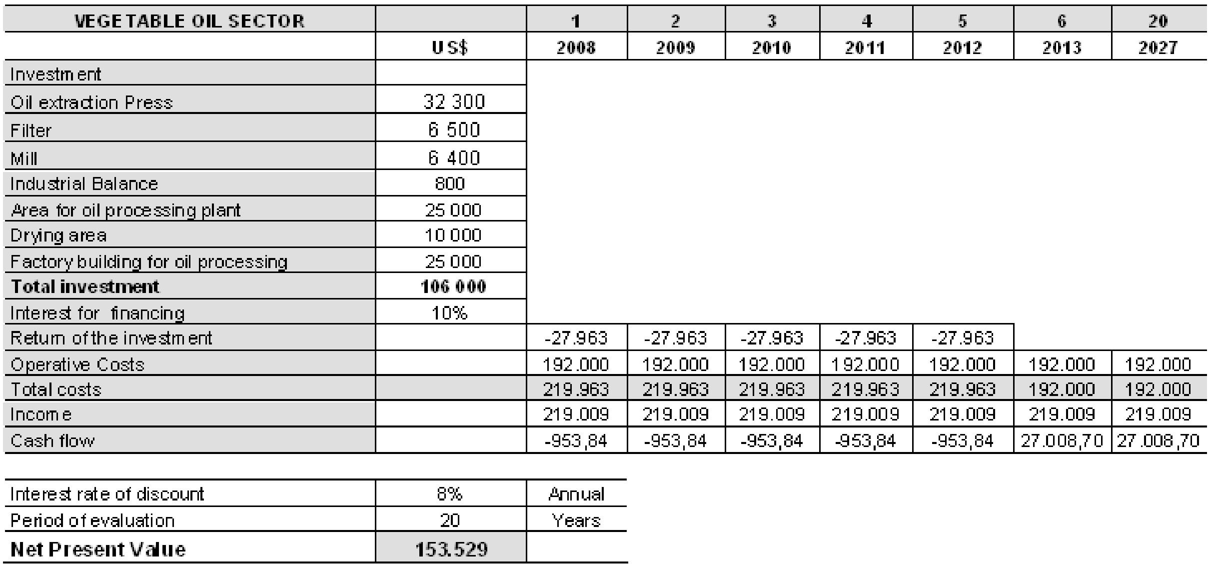
Table XI: Cost and benefits of the vegetable oil sector

Costs and Benefits of the vegetable oil sector	
Costs	US $
Investment costs	
Annual operative costs (US $/t)	240
Cost from the seed	180
Cost from transport	30
Operative and administrative expenses	10
Amortization from the equipment and goods	20
Total annual operative costs (800 tons)	192, 000
Revenues	US $/t
Revenue per ton of jatropha seeds	274[a]
Vegetable oil (326 litre – 33 % efficiency)	228[a]
Jatropha meal for fertilizing (700kg)	46[a]
Total annual revenue (800 tons)	219 000
Period evaluation (years)	20
Interest Rate of discount	8 %
Net Present Value (US $)	153 529

[a] Figures are rounded.

Source: own illustration of the author based on results of the CBA

Table XII: Calculation of the CBA of the vegetable oil sector



VEGETABLE OIL SECTOR		1	2	3	4	5	6	20
	US$	2008	2009	2010	2011	2012	2013	2027
Investment								
Oil extraction Press	32 300							
Filter	6 500							
Mill	6 400							
Industrial Balance	800							
Area for oil processing plant	25 000							
Drying area	10 000							
Factory building for oil processing	25 000							
Total investment	**106 000**							
Interest for financing	10%							
Return of the investment		-27.963	-27.963	-27.963	-27.963	-27.963		
Operative Costs		192.000	192.000	192.000	192.000	192.000	192.000	192.000
Total costs		219.963	219.963	219.963	219.963	219.963	192.000	192.000
Income		219.009	219.009	219.009	219.009	219.009	219.009	219.009
Cash flow		-953,84	-953,84	-953,84	-953,84	-953,84	27.008,70	27.008,70

Interest rate of discount	8%	Annual
Period of evaluation	20	Years
Net Present Value	**153.529**	

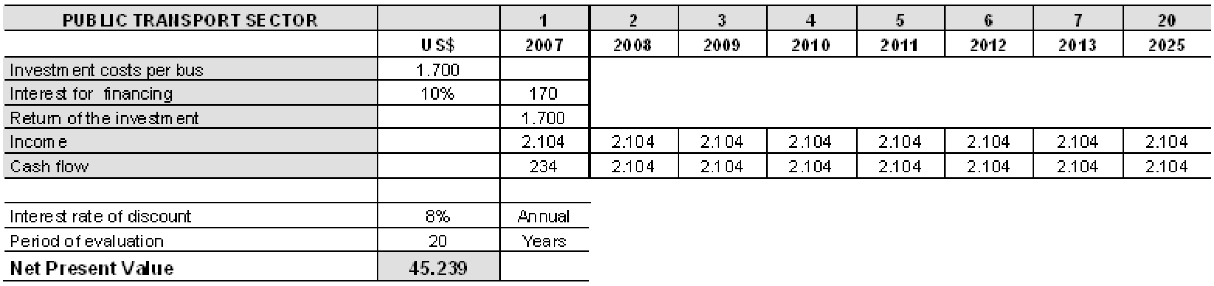
Source: Own calculation based on figures received by the DED (2008).

Table XIII: Cost and benefits of the public transport sector

Costs and Benefits of the public transport sector	
Costs	US $
Diesel D2 (US $/litre)	0.87 [a]
Jatropha / vegetable oil (US $/litre)	0.70
Consumption and Expenses	
Consumption per day/ per year (litre)	45 / 14 400 (320 days)
Annual Expense for Diesel D2 (US $/ year)	12 456
Annual Expense for jatropha oil (US $/ year)	10 080
Annual Savings (US $/ year)	2 367
Investment costs (US $)	1 700
Amortization from the investment (months)	7.63
Period evaluation (years)	20
Interest Rate of discount	8 %
Net Present Value (US $)	45 239

[a] Figures are rounded. Source: own illustration of the author based on results of the CBA

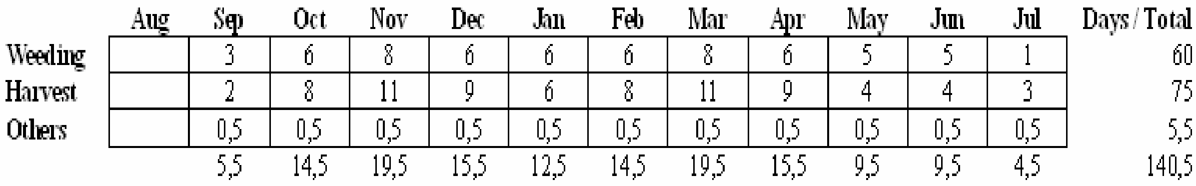
Table XIV: Calculation of the CBA of the public transport sector



PUBLIC TRANSPORT SECTOR		1	2	3	4	5	6	7	20
	US$	2007	2008	2009	2010	2011	2012	2013	2025
Investment costs per bus	1.700								
Interest for financing	10%	170							
Return of the investment		1.700							
Income		2.104	2.104	2.104	2.104	2.104	2.104	2.104	2.104
Cash flow		234	2.104	2.104	2.104	2.104	2.104	2.104	2.104
Interest rate of discount	8%	Annual							
Period of evaluation	20	Years							
Net Present Value	**45.239**								

Source: Own calculation based on figures received by the DED (2008).

Table XV: Labour demand for Jatropha in case of a yield of 6 tons per hectare



	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Days / Total
Weeding		3	6	8	6	6	6	8	6	5	5	1	60
Harvest		2	8	11	9	6	8	11	9	4	4	3	75
Others		0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	5,5
		5,5	14,5	19,5	15,5	12,5	14,5	19,5	15,5	9,5	9,5	4,5	140,5

Source: own illustration, based on figures received by the SKODDOW et al. (2008) and the ‘Note’ of Table 19 (see Table 19).

Table XVI: Required Area needed to cover the National Demand for Conventional Diesel by means of Jatropha-based Biodiesel, 2008 – 2013

Year	Diesel Consumption (mill. gallons/year)	Biodiesel B2 and B5 consumption (mill. gallons/year)	Area of Jatropha (ha) for the production of B2 and B5	Area of Jatropha (ha) for the production of B100
2008	965.0	19.3	36,525.4	1,826,267.9
2009	1,060.0	21.2	40,121.1	2,006,056.0
2010	1,090.0	21.8	41,256.6	2,062,831.2
2011	1,138.0	56.9	107,683.6	2,153,671.5
2012	1,168.0	58.4	110,522.3	2,210,446.6
2013	1,212.0	60.6	114,685.8	2,293,716.9

Note: Calculations are based on a yield of 6 tons/ha of jatropha seeds containing on average 33 % oil (around 2,000 litres or 528.4 gallons of jatropha oil per hectare)
Source: own calculation, based on ARÉVALO et al. (2007), p. 13.

Appendix II

Code I: Scenario a – Base Case

```
$Title Farm Level Model San Martín, Peru (DEMO1,SEQ=91)
*$Stitle Crop Data

$Ontext

GAMS model for assessing the profitability of jatropha (scenario a - base cas»
e)

David van der Zaan

$Offtext


Sets  c crops   / rice, maize, cassava1,cassava2, beans,
                   banana, citrus, falland  /

      d(c) dcrops / rice, maize, cassava1, cassava2,
                          beans, banana /

      p(c) pcrops / citrus /

      a(c) acrops / rice, banana /

      b(c) bcrops / maize, cassava1 /

      f(c) ccrops / beans, cassava2 /

      t period  / jan, feb, mar, apr, may, jun,
                  jul, aug, sep, oct, nov, dec  /


Table laborreq(t,c) crop and fallow land labor requirements (man-days per hec»
tare)

     rice   maize  cassava1 cassava2  beans  banana  citrus   falland
jan   25.    16.    10.       10.             10.
feb                  0.        0.      14.    12.
mar                  0.        0.      20.     0.     15.
apr                 10.       10.       0.     0.     30.5
may                  0.        0.      10.    12.     30.5
jun                  0.        0.      30.     0.     30.5
jul                 21.       21.              0.     30.5      10
aug                 21.       21.             12.               11
sep   10.   10.                               10.5
oct   10.   10.                               10.5
nov   10.    0.      4.        4.             10.5
dec    0.    0.      0.        0.             10.5


Parameters yield(c) crop yield (tons per hectare) /
                    rice  = 2.0, maize = 2.0,  cassava1 = 13.0, cassava2 = 13»
.0
                    beans = 1.0, banana = 9.6 , citrus  = 7.3    /

           price(c) crop prices (dollars per ton)             /
                    rice  = 130, maize  = 111,  cassava1 = 46, cassava2 = 46
                    beans = 435, banana  =  56,  citrus = 111 /

* farm and labour data:

Scalars land    farm size (hectares)                        /  9.4 /
```

```
        famlab  family labor available (days per month)    /  63  /
        twage   temporary labor wage  (dollars per day)    /  5   /
        fwage   family labor wage                          /  4   /


$Stitle endogenous variables and equations

Variables  xcrop(c)   cropping activity          (hectares)
           yfarm      farm income                (dollars)
           revenue    value of production        (dollars)
           labcost    labor cost                 (dollars)
           flab(t)    family labor use           (days)
           tlab(t)    temporary labor            (days)

Positive Variable xcrop, flab ,fout, tlab

Equations  landbal(t)   land balance               (hectares)
           laborbal(t)  labor balance              (days)
           flabor(t)    family labor balance       (days)
           arev         revenue accounting         (dollars)
           alab         labor cost accounting      (dollars)
           income       income definition          (dollars)
           landprep(t)  landpreparation demand     (hectares)
           cycle1       rice-plantain-plantain     (hectares)
           cycle2       maize-cassava1-cassava1    (hectares)
           cycle3       beans-cassava2-cassava2    (hectares);

landbal(t)..   sum(c, xcrop(c))  =l= land

laborbal(t)..  sum(c, xcrop(c)*laborreq(t,c)) =l= flab(t) + tlab(t)

flabor(t)..    flab(t) =l= famlab

arev..         revenue =e= sum(c, xcrop(c)*yield(c)*price(c))

alab..         labcost =e= sum(t, tlab(t)*twage) + sum(t, flab(t)*fwage)

income..       yfarm   =e= revenue - labcost

landprep(t)..  xcrop("falland") =g= sum(d, xcrop(d))

cycle1..       2*xcrop("rice") =e= xcrop("banana")

cycle2..       2*xcrop("maize") =e= xcrop("cassava1")

cycle3..       2*xcrop("beans") =e= xcrop("cassava2")


Model demo1 farm labor model / all /;

xcrop.LO("cassava1") = 0.5;
xcrop.LO("cassava2") = 0.2;
xcrop.LO("maize") = 0.25;
xcrop.LO("beans") = 0.1;
xcrop.LO("banana") = 1.;
xcrop.LO("rice") = 0.5;
xcrop.LO("citrus") = 0.42;
xcrop.UP("citrus") = 0.42;
tlab.UP(t) = 0.;


```

```
Solve demo1 using lp maximizing yfarm;

Sets crep    / landuse, output, revenue, profit, profitpc, profitclear /
     lrep    / demand,  family, temporary
               unused /
     cycrep  /cyc1profitclear,cyc2profitclear,cyc3profitclear,
                 cyc1profitpc, cyc2profitpc, cyc3profitpc,
                 cyc1landuse, cyc2landuse, cyc3landuse  /

Parameters  croprep crop report summary
            labrep  labor report summary(days)
           cyclerep    cycle report summary;

croprep("landuse",c)  = xcrop.l(c);
croprep("output",c)   = xcrop.l(c)*yield(c);
croprep("revenue",c)  = croprep("output",c)*price(c);
croprep("profit",c)   = croprep("revenue",c)- xcrop.l(c) * sum(t,laborreq(t,c»
)) * fwage ;
alias(c,cc);
croprep("profitpc",d) = (croprep("profit",d) - xcrop.l(d) * 21 * fwage) * 100»
 / sum(cc, croprep("profit",cc));
alias(c,ccc);
croprep("profitpc",p) = croprep("profit",p) * 100 / (sum(ccc, croprep("profit»
",ccc)));
alias(c,cccc);
croprep("profitclear",d)   = croprep("profitpc",d) * (sum(cccc, croprep("prof»
it",cccc))) / 100 ;
croprep("profitclear",p)   = croprep("profit",p) ;
croprep(crep,"total") = sum(c, croprep(crep,c));

labrep(t,"demand")    = sum(c, xcrop.l(c)*laborreq(t,c));
labrep(t,"family")    = flab.l(t);
labrep(t,"temporary") = tlab.l(t);
labrep(t,"unused")    = -laborbal.l(t);
labrep("total",lrep)  = sum(t, labrep(t,lrep));

cyclerep("cyc1profitclear",a) = croprep("profitclear",a) ;
cyclerep("cyc2profitclear",b)  = croprep("profitclear",b) ;
cyclerep("cyc3profitclear",f)  = croprep("profitclear",f) ;

cyclerep("cyc1profitpc",a)  = croprep("profitpc",a) ;
cyclerep("cyc2profitpc",b)  = croprep("profitpc",b) ;
cyclerep("cyc3profitpc",f)  = croprep("profitpc",f) ;

cyclerep("cyc1landuse",a)  = croprep("landuse",a) ;
cyclerep("cyc2landuse",b)  = croprep("landuse",b) ;
cyclerep("cyc3landuse",f)  = croprep("landuse",f) ;

cyclerep(cycrep,"total") = sum(cc, cyclerep(cycrep,cc));

Display "landuse      [ha]"
        "output       [t] "
        "revenue      [$] "
        "profit       [$] "
        "profitpc     [%] "
        "profitclear  [$] ", croprep, labrep, cyclerep;
display tlab.l  ;
```

Code II: Scenario b – Subcase 1[109]

```
$Title Farm Level Model San Martín, Peru (DEMO1,SEQ=91)
*$Stitle Crop Data

$Ontext

GAMS model for assessing the profitability of jatropha (scenario b - subcase »
1)

David van der Zaan

$Offtext


Sets  c crops   / rice, maize, cassava1,cassava2, beans,
                   banana, citrus, falland, jatropha  /

      d(c) dcrops / rice, maize, cassava1, cassava2,
                          beans, banana /

      p(c) pcrops / citrus, jatropha /

      a(c) acrops / rice, banana /

      b(c) bcrops / maize, cassava1 /

      f(c) ccrops / beans, cassava2 /

      t period  / jan, feb, mar, apr, may, jun,
                  jul, aug, sep, oct, nov, dec  /

Table laborreq(t,c) crop and fallow land labor requirements (man-days per hec»
tare)

     rice   maize  cassava1 cassava2  beans  banana  citrus   falland   jatro»
pha
jan   25.    16.    10.       10.             10.                         12
feb                  0.        0.      14.    12.                         13.»
8
mar                  0.        0.      20.     0.     15.                 18.»
6
apr                 10.       10.       0.     0.     30.5                14.»
8
may                  0.        0.      10.    12.     30.5                9.2
jun                  0.        0.      30.     0.     30.5                9.2
jul                 21.       21.              0.     30.5      10        4.3
aug                 21.       21.             12.               11        0.
sep   10.   10.                               10.5                        5.3
oct   10.   10.                               10.5                        13.»
8
nov   10.    0.      4.        4.             10.5                        18.»
6
dec    0.    0.      0.        0.             10.5                        14.»
8

Parameters yield(c) crop yield (tons per hectare) /
                    rice  = 2.0, maize = 2.0,  cassava1 = 13.0, cassava2 = 13»
.0
                    beans = 1.0, banana = 9.6 , citrus  = 7.3, jatropha = 5.5»
    /

           price(c) crop prices (dollars per ton)             /
```

---

[109] * (5.5 t/ha; US$ 180/t)

```
                    rice  = 130, maize  = 111,  cassava1 = 46, cassava2 = 46
                    beans = 435, banana  =  56,  citrus = 111, jatropha = 180»
 /

           miscost(c) misc cash costs (dollars per hectare)   /
           jatropha = 182 /;

* farm and labour data:

Scalars land    farm size (hectares)                       /  9.4  /
        famlab  family labor available (days per month)    / 63   /
        twage   temporary labor wage  (dollars per day)    /  5  /
        fwage   family labor wage                          / 4 /


$Stitle endogenous variables and equations

Variables  xcrop(c)   cropping activity         (hectares)
           yfarm      farm income               (dollars)
           revenue    value of production       (dollars)
           labcost    labor cost                (dollars)
           flab(t)    family labor use          (days)
           tlab(t)    temporary labor           (days)

Positive Variable xcrop, flab ,fout, tlab

Equations  landbal(t)   land balance              (hectares)
           laborbal(t)  labor balance             (days)
           flabor(t)    family labor balance      (days)
           arev         revenue accounting        (dollars)
           alab         labor cost accounting     (dollars)
           income       income definition         (dollars)
           landprep(t)  landpreparation demand    (hectares)
           cycle1       rice-plantain-plantain    (hectares)
           cycle2       maize-cassava1-cassava1   (hectares)
           cycle3       beans-cassava2-cassava2   (hectares);

landbal(t)..   sum(c, xcrop(c))  =l= land             ;

laborbal(t)..  sum(c, xcrop(c)*laborreq(t,c)) =l= flab(t) + tlab(t);

flabor(t)..    flab(t) =l= famlab                       ;

arev..         revenue =e= sum(c, xcrop(c)*yield(c)*price(c))     ;

alab..         labcost =e= sum(t, tlab(t)*twage) + sum(t, flab(t)*fwage) ;

income..       yfarm   =e= revenue - labcost                                »
            ;

landprep(t)..  xcrop("falland") =g= sum(d, xcrop(d)) ;

cycle1..       2*xcrop("rice") =e= xcrop("banana");

cycle2..       2*xcrop("maize") =e= xcrop("cassava1");

cycle3..       2*xcrop("beans") =e= xcrop("cassava2");


Model demo1 farm labor model / all /;

```

```
xcrop.LO("cassava1") = 0.5;
xcrop.LO("cassava2") = 0.42;
xcrop.LO("maize") = 0.25;
xcrop.LO("beans") = 0.21;
xcrop.LO("banana") = 1;
xcrop.LO("rice") = 0.5;
xcrop.UP("cassava1") = 0.5;
xcrop.UP("cassava2") = 0.42;
xcrop.UP("maize") = 0.25;
xcrop.UP("beans") = 0.21;
xcrop.UP("banana") = 1;
xcrop.UP("rice") = 0.5;
xcrop.LO("citrus") = 0.42;
xcrop.UP("citrus") = 0.42;
tlab.UP(t) = 0.;

Solve demo1 using lp maximizing yfarm ;

Sets crep    / landuse, output, revenue, profit, profitpc, profitclear /
     lrep    / demand,  family, temporary
               unused /
     cycrep  /cyc1profitclear,cyc2profitclear,cyc3profitclear,
                 cyc1profitpc, cyc2profitpc, cyc3profitpc,
                 cyc1landuse, cyc2landuse, cyc3landuse  /

Parameters  croprep crop report summary
            labrep  labor report summary(days)
           cyclerep    cycle report summary;

croprep("landuse",c)  = xcrop.l(c);
croprep("output",c)   = xcrop.l(c)*yield(c);
croprep("revenue",c)  = croprep("output",c)*price(c);
croprep("profit",c)   = croprep("revenue",c)- xcrop.l(c) * sum(t,laborreq(t,c»
)) * fwage ;
alias(c,cc);
croprep("profitpc",d) = (croprep("profit",d) - xcrop.l(d) * 21 * fwage) * 100»
 / sum(cc, croprep("profit",cc));
alias(c,ccc);
croprep("profitpc",p) = croprep("profit",p) * 100 / (sum(ccc, croprep("profit»
",ccc)));
alias(c,cccc);
croprep("profitclear",d)   = croprep("profitpc",d) * (sum(cccc, croprep("prof»
it",cccc))) / 100 ;
croprep("profitclear",p)   = croprep("profit",p) ;
croprep(crep,"total") = sum(c, croprep(crep,c));

labrep(t,"demand")    = sum(c, xcrop.l(c)*laborreq(t,c));
labrep(t,"family")    = flab.l(t);
labrep(t,"temporary") = tlab.l(t);
labrep(t,"unused")    = -laborbal.l(t);
labrep("total",lrep)  = sum(t, labrep(t,lrep));


cyclerep("cyc1profitclear",a) = croprep("profitclear",a) ;
cyclerep("cyc2profitclear",b)  = croprep("profitclear",b) ;
cyclerep("cyc3profitclear",f)  = croprep("profitclear",f) ;

cyclerep("cyc1profitpc",a)  = croprep("profitpc",a) ;
cyclerep("cyc2profitpc",b)  = croprep("profitpc",b) ;
cyclerep("cyc3profitpc",f)  = croprep("profitpc",f) ;

```

```
cyclerep("cyc1landuse",a)  = croprep("landuse",a) ;
cyclerep("cyc2landuse",b)  = croprep("landuse",b) ;
cyclerep("cyc3landuse",f)  = croprep("landuse",f) ;

cyclerep(cycrep,"total") = sum(cc, cyclerep(cycrep,cc));


Display "landuse      [ha]"
        "output       [t] "
        "revenue      [$] "
        "profit       [$] "
        "profitpc     [%] "
        "profitclear  [$] ", croprep, labrep, cyclerep;
display tlab.l  ;
```

Code III: Scenario b – Subcase 2[110]

```
$Title Farm Level Model San Martín, Peru (DEMO1,SEQ=91)
*$Stitle Crop Data

$Ontext

GAMS model for assessing the profitability of jatropha (scenario b - subcase »
2)

David van der Zaan

$Offtext


Sets  c crops   / rice, maize, cassava1,cassava2, beans,
                   banana, citrus, falland, jatropha  /

      d(c) dcrops / rice, maize, cassava1, cassava2,
                          beans, banana /

      p(c) pcrops / citrus, jatropha /

      a(c) acrops / rice, banana /

      b(c) bcrops / maize, cassava1 /

      f(c) ccrops / beans, cassava2 /

      t period  / jan, feb, mar, apr, may, jun,
                  jul, aug, sep, oct, nov, dec  /


Table laborreq(t,c) crop and fallow land labor requirements (man-days per hec»
tare)

     rice   maize  cassava1 cassava2  beans  banana  citrus   falland   jatro»
pha
jan   25.    16.    10.       10.             10.                         12
feb                  0.        0.      14.    12.                         13.»
8
mar                  0.        0.      20.     0.     15.                 18.»
6
apr                 10.       10.       0.     0.     30.5                14.»
8
may                  0.        0.      10.    12.     30.5                9.2
jun                  0.        0.      30.     0.     30.5                9.2
jul                 21.       21.              0.     30.5      10        4.3
aug                 21.       21.             12.               11        0.
sep   10.   10.                               10.5                        5.3
oct   10.   10.                               10.5                        13.»
8
nov   10.    0.      4.        4.             10.5                        18.»
6
dec    0.    0.      0.        0.             10.5                        14.»
8

Parameters yield(c) crop yield (tons per hectare) /
                    rice  = 2.0, maize = 2.0,  cassava1 = 13.0, cassava2 = 13»
.0
                    beans = 1.0, banana = 9.6 , citrus  = 7.3, jatropha = 5.5»
    /

```

---

[110] * (5.5 t/ha; US$ 140/t)

```
           price(c) crop prices (dollars per ton)             /
                    rice  = 130, maize  = 111,  cassava1 = 46, cassava2 = 46
                    beans = 435, banana  =  56,  citrus = 111, jatropha = 140»
 /

           miscost(c) misc cash costs (dollars per hectare)   /
           jatropha = 182 /;

* farm and labour data:

Scalars land    farm size (hectares)                         /  9.4  /
        famlab  family labor available (days per month)      / 63   /
        twage   temporary labor wage  (dollars per day)      /  5  /
        fwage   family labor wage                            / 4 /


$Stitle endogenous variables and equations

Variables  xcrop(c)   cropping activity         (hectares)
           yfarm      farm income               (dollars)
           revenue    value of production       (dollars)
           labcost    labor cost                (dollars)
           flab(t)    family labor use          (days)
           tlab(t)    temporary labor           (days)

Positive Variable xcrop, flab ,fout, tlab

Equations  landbal(t)   land balance              (hectares)
           laborbal(t)  labor balance             (days)
           flabor(t)    family labor balance      (days)
           arev         revenue accounting        (dollars)
           alab         labor cost accounting     (dollars)
           income       income definition         (dollars)
           landprep(t)  landpreparation demand    (hectares)
           cycle1       rice-plantain-plantain    (hectares)
           cycle2       maize-cassava1-cassava1   (hectares)
           cycle3       beans-cassava2-cassava2   (hectares);

landbal(t)..   sum(c, xcrop(c))  =l= land            ;

laborbal(t)..  sum(c, xcrop(c)*laborreq(t,c)) =l= flab(t) + tlab(t);

flabor(t)..    flab(t) =l= famlab                       ;

arev..         revenue =e= sum(c, xcrop(c)*yield(c)*price(c))      ;

alab..         labcost =e= sum(t, tlab(t)*twage) + sum(t, flab(t)*fwage) ;

income..       yfarm   =e= revenue - labcost                                 »
           ;

landprep(t)..  xcrop("falland") =g= sum(d, xcrop(d)) ;

cycle1..       2*xcrop("rice") =e= xcrop("banana");

cycle2..       2*xcrop("maize") =e= xcrop("cassava1");

cycle3..       2*xcrop("beans") =e= xcrop("cassava2");


Model demo1 farm labor model / all /;
```

```
xcrop.LO("cassava1") = 0.5;
xcrop.LO("cassava2") = 0.42;
xcrop.LO("maize") = 0.25;
xcrop.LO("beans") = 0.21;
xcrop.LO("banana") = 1;
xcrop.LO("rice") = 0.5;
xcrop.UP("cassava1") = 0.5;
xcrop.UP("cassava2") = 0.42;
xcrop.UP("maize") = 0.25;
xcrop.UP("beans") = 0.21;
xcrop.UP("banana") = 1;
xcrop.UP("rice") = 0.5;
xcrop.LO("citrus") = 0.42;
xcrop.UP("citrus") = 0.42;
tlab.UP(t) = 0.;

Solve demo1 using lp maximizing yfarm;

Sets crep    / landuse, output, revenue, profit, profitpc, profitclear /
     lrep    / demand,  family, temporary
               unused /
     cycrep  /cyc1profitclear,cyc2profitclear,cyc3profitclear,
                 cyc1profitpc, cyc2profitpc, cyc3profitpc,
                 cyc1landuse, cyc2landuse, cyc3landuse  /

Parameters  croprep crop report summary
            labrep  labor report summary(days)
           cyclerep    cycle report summary;

croprep("landuse",c)  = xcrop.l(c);
croprep("output",c)   = xcrop.l(c)*yield(c);
croprep("revenue",c)  = croprep("output",c)*price(c);
croprep("profit",c)   = croprep("revenue",c)- xcrop.l(c) * sum(t,laborreq(t,c»
)) * fwage ;
alias(c,cc);
croprep("profitpc",d) = (croprep("profit",d) - xcrop.l(d) * 21 * fwage) * 100»
 / sum(cc, croprep("profit",cc));
alias(c,ccc);
croprep("profitpc",p) = croprep("profit",p) * 100 / (sum(ccc, croprep("profit»
",ccc)));
alias(c,cccc);
croprep("profitclear",d)   = croprep("profitpc",d) * (sum(cccc, croprep("prof»
it",cccc))) / 100 ;
croprep("profitclear",p)   = croprep("profit",p) ;
croprep(crep,"total") = sum(c, croprep(crep,c));

labrep(t,"demand")    = sum(c, xcrop.l(c)*laborreq(t,c));
labrep(t,"family")    = flab.l(t);
labrep(t,"temporary") = tlab.l(t);
labrep(t,"unused")    = -laborbal.l(t);
labrep("total",lrep)  = sum(t, labrep(t,lrep));


cyclerep("cyc1profitclear",a) = croprep("profitclear",a) ;
cyclerep("cyc2profitclear",b)  = croprep("profitclear",b) ;
cyclerep("cyc3profitclear",f)  = croprep("profitclear",f) ;

cyclerep("cyc1profitpc",a)  = croprep("profitpc",a) ;
cyclerep("cyc2profitpc",b)  = croprep("profitpc",b) ;
cyclerep("cyc3profitpc",f)  = croprep("profitpc",f) ;
```

```

cyclerep("cyc1landuse",a)  = croprep("landuse",a) ;
cyclerep("cyc2landuse",b)  = croprep("landuse",b) ;
cyclerep("cyc3landuse",f)  = croprep("landuse",f) ;

cyclerep(cycrep,"total") = sum(cc, cyclerep(cycrep,cc));


Display "landuse      [ha]"
        "output       [t] "
        "revenue      [$] "
        "profit       [$] "
        "profitpc     [%] "
        "profitclear  [$] ", croprep, labrep, cyclerep;
display tlab.l  ;
```

Code IV: Scenario b – Subcase 3[111]

```
$Title Farm Level Model San Martín, Peru (DEMO1,SEQ=91)
*$Stitle Crop Data

$Ontext

GAMS model for assessing the profitability of jatropha (scenario b - subcase »
3)


David van der Zaan


$Offtext


Sets  c crops   / rice, maize, cassava1,cassava2, beans,
                   banana, citrus, falland, jatropha  /

      d(c) dcrops / rice, maize, cassava1, cassava2,
                          beans, banana /

      p(c) pcrops / citrus, jatropha /

      a(c) acrops / rice, banana /

      b(c) bcrops / maize, cassava1 /

      f(c) ccrops / beans, cassava2 /

      t period  / jan, feb, mar, apr, may, jun,
                  jul, aug, sep, oct, nov, dec  /


Table laborreq(t,c) crop and fallow land labor requirements (man-days per hec»
tare)

*die arbeitstage für land preparation sind im text nicht auf ha basis sondern»
 für
* die ganzen 7 ha fallow land zu verstehen; daher habe ich die 10 u. 11 tage »
im juli
* bzw. august durch 7 geteilt, um die benötigten arbeitstage für einen ha fal»
low land zu haben
* daher 1.43 und 1.57

     rice   maize  cassava1 cassava2  beans  banana  citrus   falland   jatro»
pha
jan   25.    16.    10.       10.             10.                         10.»
2
feb                  0.        0.      14.    12.                         11.»
4
mar                  0.        0.      20.     0.     15.                 15.»
3
apr                 10.       10.       0.     0.     30.5                12.»
1
may                  0.        0.      10.    12.     30.5                8
jun                  0.        0.      30.     0.     30.5                8
jul                 21.       21.              0.     30.5      10        3.4
aug                 21.       21.             12.               11        0.
sep   10.   10.                               10.5                        4.7
oct   10.   10.                               10.5                        11.»
4
```

---

[111] * (3.7 t/ha; US$ 180/t)

```
nov   10.    0.      4.       4.            10.5                        15.»
3
dec    0.    0.      0.       0.            10.5                        12.»
1

Parameters yield(c) crop yield (tons per hectare) /
                    rice  = 2.0, maize = 2.0,  cassava1 = 13.0, cassava2 = 13»
.0
                    beans = 1.0, banana = 9.6 , citrus  = 7.3, jatropha = 3.7»
    /

           price(c) crop prices (dollars per ton)           /
                    rice  = 130, maize  = 111,  cassava1 = 46, cassava2 = 46
                    beans = 435, banana  =  56,  citrus = 111, jatropha = 180»
  /

           miscost(c) misc cash costs (dollars per hectare)   /
           jatropha = 182 /;


* farm and labour data:

Scalars land    farm size (hectares)                       /  9.4  /
        famlab  family labor available (days per month)    / 63   /
        twage   temporary labor wage  (dollars per day)    /  5  /
        fwage   family labor wage                          / 4 /


$Stitle endogenous variables and equations

Variables  xcrop(c)   cropping activity         (hectares)
           yfarm      farm income               (dollars)
           revenue    value of production       (dollars)
           labcost    labor cost                (dollars)
           flab(t)    family labor use          (days)
           tlab(t)    temporary labor           (days)

Positive Variable xcrop, flab ,fout, tlab

Equations  landbal(t)   land balance              (hectares)
           laborbal(t)  labor balance             (days)
           flabor(t)    family labor balance      (days)
           arev         revenue accounting        (dollars)
           alab         labor cost accounting     (dollars)
           income       income definition         (dollars)
           landprep(t)  landpreparation demand    (hectares)
           cycle1       rice-plantain-plantain    (hectares)
           cycle2       maize-cassava1-cassava1   (hectares)
           cycle3       beans-cassava2-cassava2   (hectares);

landbal(t)..   sum(c, xcrop(c))  =l= land            ;

laborbal(t)..  sum(c, xcrop(c)*laborreq(t,c)) =l= flab(t) + tlab(t);

flabor(t)..    flab(t) =l= famlab                   ;

arev..         revenue =e= sum(c, xcrop(c)*yield(c)*price(c))      ;

alab..         labcost =e= sum(t, tlab(t)*twage) + sum(t, flab(t)*fwage) ;

income..       yfarm   =e= revenue - labcost                           »
```

```
            ;

landprep(t)..  xcrop("falland") =g= sum(d, xcrop(d)) ;

cycle1..       2*xcrop("rice") =e= xcrop("banana");

cycle2..       2*xcrop("maize") =e= xcrop("cassava1");

cycle3..       2*xcrop("beans") =e= xcrop("cassava2");


Model demo1 farm labor model / all /;

xcrop.LO("cassava1") = 0.5;
xcrop.LO("cassava2") = 0.42;
xcrop.LO("maize") = 0.25;
xcrop.LO("beans") = 0.21;
xcrop.LO("banana") = 1;
xcrop.LO("rice") = 0.5;
xcrop.UP("cassava1") = 0.5;
xcrop.UP("cassava2") = 0.42;
xcrop.UP("maize") = 0.25;
xcrop.UP("beans") = 0.21;
xcrop.UP("banana") = 1;
xcrop.UP("rice") = 0.5;
xcrop.LO("citrus") = 0.42;
xcrop.UP("citrus") = 0.42;
tlab.UP(t) = 0.;

Solve demo1 using lp maximizing yfarm ;

Sets crep    / landuse, output, revenue, profit, profitpc, profitclear /
     lrep    / demand,  family, temporary
               unused /
     cycrep  /cyc1profitclear,cyc2profitclear,cyc3profitclear,
                 cyc1profitpc, cyc2profitpc, cyc3profitpc,
                 cyc1landuse, cyc2landuse, cyc3landuse  /

Parameters  croprep crop report summary
            labrep  labor report summary(days)
           cyclerep    cycle report summary;

croprep("landuse",c)  = xcrop.l(c);
croprep("output",c)   = xcrop.l(c)*yield(c);
croprep("revenue",c)  = croprep("output",c)*price(c);
croprep("profit",c)   = croprep("revenue",c)- xcrop.l(c) * sum(t,laborreq(t,c»
)) * fwage ;
alias(c,cc);
croprep("profitpc",d) = (croprep("profit",d) - xcrop.l(d) * 21 * fwage) * 100»
 / sum(cc, croprep("profit",cc));
alias(c,ccc);
croprep("profitpc",p) = croprep("profit",p) * 100 / (sum(ccc, croprep("profit»
",ccc)));
alias(c,cccc);
croprep("profitclear",d)    = croprep("profitpc",d) * (sum(cccc, croprep("prof»
it",cccc))) / 100 ;
croprep("profitclear",p)    = croprep("profit",p) ;
croprep(crep,"total") = sum(c, croprep(crep,c));

labrep(t,"demand")     = sum(c, xcrop.l(c)*laborreq(t,c));
labrep(t,"family")     = flab.l(t);
```

```
labrep(t,"temporary") = tlab.l(t);
labrep(t,"unused")    = -laborbal.l(t);
labrep("total",lrep)  = sum(t, labrep(t,lrep));


cyclerep("cyc1profitclear",a) = croprep("profitclear",a) ;
cyclerep("cyc2profitclear",b)  = croprep("profitclear",b) ;
cyclerep("cyc3profitclear",f)  = croprep("profitclear",f) ;

cyclerep("cyc1profitpc",a)  = croprep("profitpc",a) ;
cyclerep("cyc2profitpc",b)  = croprep("profitpc",b) ;
cyclerep("cyc3profitpc",f)  = croprep("profitpc",f) ;

cyclerep("cyc1landuse",a)  = croprep("landuse",a) ;
cyclerep("cyc2landuse",b)  = croprep("landuse",b) ;
cyclerep("cyc3landuse",f)  = croprep("landuse",f) ;

cyclerep(cycrep,"total") = sum(cc, cyclerep(cycrep,cc));


Display "landuse      [ha]"
        "output       [t] "
        "revenue      [$] "
        "profit       [$] "
        "profitpc     [%] "
        "profitclear  [$] ", croprep, labrep, cyclerep;
display tlab.l  ;
```

Code V: Scenario b – Subcase 4[112]

```
$Title Farm Level Model San Martín, Peru (DEMO1,SEQ=91)
*$Stitle Crop Data

$Ontext

GAMS model for assessing the profitability of jatropha (scenario b - subcase »
4)


David van der Zaan


$Offtext


Sets  c crops   / rice, maize, cassava1,cassava2, beans,
                   banana, citrus, falland, jatropha  /

      d(c) dcrops / rice, maize, cassava1, cassava2,
                          beans, banana /

      p(c) pcrops / citrus, jatropha /

      a(c) acrops / rice, banana /

      b(c) bcrops / maize, cassava1 /

      f(c) ccrops / beans, cassava2 /

      t period  / jan, feb, mar, apr, may, jun,
                  jul, aug, sep, oct, nov, dec  /


Table laborreq(t,c) crop and fallow land labor requirements (man-days per hec»
tare)

*die arbeitstage für land preparation sind im text nicht auf ha basis sondern»
 für
* die ganzen 7 ha fallow land zu verstehen; daher habe ich die 10 u. 11 tage »
im juli
* bzw. august durch 7 geteilt, um die benötigten arbeitstage für einen ha fal»
low land zu haben
* daher 1.43 und 1.57

     rice   maize  cassava1 cassava2  beans  banana  citrus   falland   jatro»
pha
jan   25.    16.    10.       10.            10.                          10.»
2
feb                  0.        0.      14.   12.                          11.»
4
mar                  0.        0.      20.    0.     15.                  15.»
3
apr                 10.       10.       0.    0.     30.5                 12.»
1
may                  0.        0.      10.   12.     30.5                 8
jun                  0.        0.      30.    0.     30.5                 8
jul                 21.       21.             0.     30.5      10         3.4
aug                 21.       21.            12.               11         0.
sep   10.   10.                              10.5                         4.7
oct   10.   10.                              10.5                         11.»
4
```

---

[112] * (3.7 t/ha; US$ 140/t)

```
nov   10.    0.      4.        4.             10.5                           15.»
3
dec    0.    0.      0.        0.             10.5                           12.»
1

Parameters yield(c) crop yield (tons per hectare) /
                    rice  = 2.0, maize = 2.0,  cassava1 = 13.0, cassava2 = 13»
.0
                    beans = 1.0, banana = 9.6 , citrus  = 7.3, jatropha = 3.7»
    /

           price(c) crop prices (dollars per ton)             /
                    rice  = 130, maize  = 111,  cassava1 = 46, cassava2 = 46
                    beans = 435, banana  =  56,  citrus = 111, jatropha = 140»
 /

           miscost(c) misc cash costs (dollars per hectare)   /
           jatropha = 182 /;


* farm and labour data:

Scalars land    farm size (hectares)                           /  9.4  /
        famlab  family labor available (days per month)    / 63   /
        twage   temporary labor wage  (dollars per day)    /  5  /
        fwage   family labor wage                          / 4 /


$Stitle endogenous variables and equations

Variables  xcrop(c)   cropping activity         (hectares)
           yfarm      farm income               (dollars)
           revenue    value of production       (dollars)
           labcost    labor cost                (dollars)
           flab(t)    family labor use          (days)
           tlab(t)    temporary labor           (days)

Positive Variable xcrop, flab ,fout, tlab

Equations  landbal(t)   land balance              (hectares)
           laborbal(t)  labor balance             (days)
           flabor(t)    family labor balance      (days)
           arev         revenue accounting        (dollars)
           alab         labor cost accounting     (dollars)
           income       income definition         (dollars)
           landprep(t)  landpreparation demand    (hectares)
           cycle1       rice-plantain-plantain    (hectares)
           cycle2       maize-cassava1-cassava1   (hectares)
           cycle3       beans-cassava2-cassava2   (hectares);

landbal(t)..   sum(c, xcrop(c))  =l= land             ;

laborbal(t)..  sum(c, xcrop(c)*laborreq(t,c)) =l= flab(t) + tlab(t);

flabor(t)..    flab(t) =l= famlab                       ;

arev..         revenue =e= sum(c, xcrop(c)*yield(c)*price(c))      ;

alab..         labcost =e= sum(t, tlab(t)*twage) + sum(t, flab(t)*fwage) ;

income..       yfarm   =e= revenue - labcost                                 »
```

```
            ;

landprep(t)..  xcrop("falland") =g= sum(d, xcrop(d)) ;

cycle1..       2*xcrop("rice") =e= xcrop("banana");

cycle2..       2*xcrop("maize") =e= xcrop("cassava1");

cycle3..       2*xcrop("beans") =e= xcrop("cassava2");


Model demo1 farm labor model / all /;

xcrop.LO("cassava1") = 0.5;
xcrop.LO("cassava2") = 0.42;
xcrop.LO("maize") = 0.25;
xcrop.LO("beans") = 0.21;
xcrop.LO("banana") = 1;
xcrop.LO("rice") = 0.5;
xcrop.UP("cassava1") = 0.5;
xcrop.UP("cassava2") = 0.42;
xcrop.UP("maize") = 0.25;
xcrop.UP("beans") = 0.21;
xcrop.UP("banana") = 1;
xcrop.UP("rice") = 0.5;
xcrop.LO("citrus") = 0.42;
xcrop.UP("citrus") = 0.42;
tlab.UP(t) = 0.;


Solve demo1 using lp maximizing yfarm ;

Sets crep    / landuse, output, revenue, profit, profitpc, profitclear /
     lrep    / demand,  family, temporary
               unused /
     cycrep  /cyc1profitclear,cyc2profitclear,cyc3profitclear,
                 cyc1profitpc, cyc2profitpc, cyc3profitpc,
                 cyc1landuse, cyc2landuse, cyc3landuse  /

Parameters  croprep crop report summary
            labrep  labor report summary(days)
           cyclerep    cycle report summary;

croprep("landuse",c)  = xcrop.l(c);
croprep("output",c)   = xcrop.l(c)*yield(c);
croprep("revenue",c)  = croprep("output",c)*price(c);
croprep("profit",c)   = croprep("revenue",c)- xcrop.l(c) * sum(t,laborreq(t,c»
)) * fwage ;
alias(c,cc);
croprep("profitpc",d) = (croprep("profit",d) - xcrop.l(d) * 21 * fwage) * 100»
 / sum(cc, croprep("profit",cc));
alias(c,ccc);
croprep("profitpc",p) = croprep("profit",p) * 100 / (sum(ccc, croprep("profit»
",ccc)));
alias(c,cccc);
croprep("profitclear",d)   = croprep("profitpc",d) * (sum(cccc, croprep("prof»
it",cccc))) / 100 ;
croprep("profitclear",p)   = croprep("profit",p) ;
croprep(crep,"total") = sum(c, croprep(crep,c));

labrep(t,"demand")    = sum(c, xcrop.l(c)*laborreq(t,c));
```

```
labrep(t,"family")    = flab.l(t);
labrep(t,"temporary") = tlab.l(t);
labrep(t,"unused")    = -laborbal.l(t);
labrep("total",lrep)  = sum(t, labrep(t,lrep));


cyclerep("cyc1profitclear",a) = croprep("profitclear",a) ;
cyclerep("cyc2profitclear",b)  = croprep("profitclear",b) ;
cyclerep("cyc3profitclear",f)  = croprep("profitclear",f) ;

cyclerep("cyc1profitpc",a)  = croprep("profitpc",a) ;
cyclerep("cyc2profitpc",b)  = croprep("profitpc",b) ;
cyclerep("cyc3profitpc",f)  = croprep("profitpc",f) ;

cyclerep("cyc1landuse",a)  = croprep("landuse",a) ;
cyclerep("cyc2landuse",b)  = croprep("landuse",b) ;
cyclerep("cyc3landuse",f)  = croprep("landuse",f) ;

cyclerep(cycrep,"total") = sum(cc, cyclerep(cycrep,cc));


Display "landuse      [ha]"
        "output       [t] "
        "revenue      [$] "
        "profit       [$] "
        "profitpc     [%] "
        "profitclear  [$] ", croprep, labrep, cyclerep;
display tlab.l  ;
```

Code VI: Scenario c – Subcase 1[113]

```
$Title Farm Level Model San Martín, Peru (DEMO1,SEQ=91)
*$Stitle Crop Data

$Ontext

GAMS model for assessing the profitability of jatropha (scenario c - subcase »
1)


David van der Zaan


$Offtext


Sets  c crops   / rice, maize, cassava1,cassava2, beans,
                   banana, citrus, falland, jatropha  /

      d(c) dcrops / rice, maize, cassava1, cassava2,
                          beans, banana /

      p(c) pcrops / citrus, jatropha /

      a(c) acrops / rice, banana /

      b(c) bcrops / maize, cassava1 /

      f(c) ccrops / beans, cassava2 /

      t period  / jan, feb, mar, apr, may, jun,
                  jul, aug, sep, oct, nov, dec  /

Table laborreq(t,c) crop and fallow land labor requirements (man-days per hec»
tare)

     rice   maize  cassava1 cassava2  beans  banana  citrus   falland   jatro»
pha
jan   25.    16.    10.       10.            10.                         12
feb                  0.        0.      14.   12.                         13.»
8
mar                  0.        0.      20.    0.     15.                 18.»
6
apr                 10.       10.       0.    0.     30.5                14.»
8
may                  0.        0.      10.   12.     30.5                9.2
jun                  0.        0.      30.    0.     30.5                9.2
jul                 21.       21.             0.     30.5      10        4.3
aug                 21.       21.            12.               11        0.
sep   10.   10.                              10.5                        5.3
oct   10.   10.                              10.5                        13.»
8
nov   10.    0.      4.        4.            10.5                        18.»
6
dec    0.    0.      0.        0.            10.5                        14.»
8

Parameters yield(c)  crop yield (tons per hectare) /
                    rice  = 2.0, maize = 2.0,  cassava1 = 13.0, cassava2 = 13»
.0
                    beans = 1.0, banana = 9.6 , citrus  = 7.3, jatropha = 5.5»
    /
```

---

[113] * (5.5 t/ha; US$ 180/t)

```

           price(c) crop prices (dollars per ton)             /
                    rice  = 130, maize  = 111,  cassava1 = 46, cassava2 = 46
                    beans = 435, banana  =  56,  citrus = 111, jatropha = 180»
 /

           miscost(c) misc cash costs (dollars per hectare)   /
           jatropha = 182 /;

* farm and labour data:

Scalars land    farm size (hectares)                        /  9.4  /
        famlab  family labor available (days per month)     / 63   /
        twage   temporary labor wage  (dollars per day)     /  5  /
        fwage   family labor wage                           / 4 /


$Stitle endogenous variables and equations

Variables  xcrop(c)   cropping activity         (hectares)
           yfarm      farm income               (dollars)
           revenue    value of production       (dollars)
           labcost    labor cost                (dollars)
           flab(t)    family labor use          (days)
           tlab(t)    temporary labor           (days)

Positive Variable xcrop, flab ,fout, tlab

Equations  landbal(t)   land balance              (hectares)
           laborbal(t)  labor balance             (days)
           flabor(t)    family labor balance      (days)
           arev         revenue accounting        (dollars)
           alab         labor cost accounting     (dollars)
           income       income definition         (dollars)
           landprep(t)  landpreparation demand    (hectares)
           cycle1       rice-plantain-plantain    (hectares)
           cycle2       maize-cassava1-cassava1   (hectares)
           cycle3       beans-cassava2-cassava2   (hectares);

landbal(t)..   sum(c, xcrop(c))  =l= land             ;

laborbal(t)..  sum(c, xcrop(c)*laborreq(t,c)) =l= flab(t) + tlab(t);

flabor(t)..    flab(t) =l= famlab                       ;

arev..         revenue =e= sum(c, xcrop(c)*yield(c)*price(c))      ;

alab..         labcost =e= sum(t, tlab(t)*twage) + sum(t, flab(t)*fwage) ;

income..       yfarm   =e= revenue - labcost                                »
            ;

landprep(t)..  xcrop("falland") =g= sum(d, xcrop(d)) ;

cycle1..       2*xcrop("rice") =e= xcrop("banana");

cycle2..       2*xcrop("maize") =e= xcrop("cassava1");

cycle3..       2*xcrop("beans") =e= xcrop("cassava2");


```

```
Model demo1 farm labor model / all /;

xcrop.LO("cassava1") = 0.5;
xcrop.LO("cassava2") = 0.2;
xcrop.LO("maize") = 0.25;
xcrop.LO("beans") = 0.1;
xcrop.LO("banana") = 1;
xcrop.LO("rice") = 0.5;
xcrop.UP("citrus") = 0.42;
tlab.UP(t) = 0.;

Solve demo1 using lp maximizing yfarm ;

Sets crep    / landuse, output, revenue, profit, profitpc, profitclear /
     lrep    / demand,  family, temporary
               unused /
     cycrep  /cyc1profitclear,cyc2profitclear,cyc3profitclear,
                 cyc1profitpc, cyc2profitpc, cyc3profitpc,
                 cyc1landuse, cyc2landuse, cyc3landuse  /

Parameters  croprep crop report summary
            labrep  labor report summary(days)
           cyclerep    cycle report summary;

croprep("landuse",c)  = xcrop.l(c);
croprep("output",c)   = xcrop.l(c)*yield(c);
croprep("revenue",c)  = croprep("output",c)*price(c);
croprep("profit",c)   = croprep("revenue",c)- xcrop.l(c) * sum(t,laborreq(t,c»
)) * fwage ;
alias(c,cc);
croprep("profitpc",d) = (croprep("profit",d) - xcrop.l(d) * 21 * fwage) * 100»
 / sum(cc, croprep("profit",cc));
alias(c,ccc);
croprep("profitpc",p) = croprep("profit",p) * 100 / (sum(ccc, croprep("profit»
",ccc)));
alias(c,cccc);
croprep("profitclear",d)   = croprep("profitpc",d) * (sum(cccc, croprep("prof»
it",cccc))) / 100 ;
croprep("profitclear",p)   = croprep("profit",p) ;
croprep(crep,"total") = sum(c, croprep(crep,c));

labrep(t,"demand")    = sum(c, xcrop.l(c)*laborreq(t,c));
labrep(t,"family")    = flab.l(t);
labrep(t,"temporary") = tlab.l(t);
labrep(t,"unused")    = -laborbal.l(t);
labrep("total",lrep)  = sum(t, labrep(t,lrep));


cyclerep("cyc1profitclear",a) = croprep("profitclear",a) ;
cyclerep("cyc2profitclear",b)  = croprep("profitclear",b) ;
cyclerep("cyc3profitclear",f)  = croprep("profitclear",f) ;

cyclerep("cyc1profitpc",a)  = croprep("profitpc",a) ;
cyclerep("cyc2profitpc",b)  = croprep("profitpc",b) ;
cyclerep("cyc3profitpc",f)  = croprep("profitpc",f) ;

cyclerep("cyc1landuse",a)  = croprep("landuse",a) ;
cyclerep("cyc2landuse",b)  = croprep("landuse",b) ;
cyclerep("cyc3landuse",f)  = croprep("landuse",f) ;

cyclerep(cycrep,"total") = sum(cc, cyclerep(cycrep,cc));
```

```


Display "landuse      [ha]"
        "output       [t] "
        "revenue      [$] "
        "profit       [$] "
        "profitpc     [%] "
        "profitclear  [$] ", croprep, labrep, cyclerep;
display tlab.l  ;
```

Code VII: Scenario c – Subcase 2[114]

```
$Title Farm Level Model San Martín, Peru (DEMO1,SEQ=91)
*$Stitle Crop Data

$Ontext

GAMS model for assessing the profitability of jatropha (scenario c - subcase »
2)


David van der Zaan


$Offtext


Sets  c crops   / rice, maize, cassava1,cassava2, beans,
                   banana, citrus, falland, jatropha  /

      d(c) dcrops / rice, maize, cassava1, cassava2,
                          beans, banana /

      p(c) pcrops / citrus, jatropha /

      a(c) acrops / rice, banana /

      b(c) bcrops / maize, cassava1 /

      f(c) ccrops / beans, cassava2 /

      t period  / jan, feb, mar, apr, may, jun,
                  jul, aug, sep, oct, nov, dec  /

Table laborreq(t,c) crop and fallow land labor requirements (man-days per hec»
tare)

     rice   maize  cassava1 cassava2  beans  banana  citrus   falland   jatro»
pha
jan   25.    16.    10.       10.             10.                         12
feb                  0.        0.      14.    12.                         13.»
8
mar                  0.        0.      20.     0.     15.                 18.»
6
apr                 10.       10.       0.     0.     30.5                14.»
8
may                  0.        0.      10.    12.     30.5                9.2
jun                  0.        0.      30.     0.     30.5                9.2
jul                 21.       21.              0.     30.5      10        4.3
aug                 21.       21.             12.               11        0.
sep   10.   10.                               10.5                        5.3
oct   10.   10.                               10.5                        13.»
8
nov   10.    0.      4.        4.             10.5                        18.»
6
dec    0.    0.      0.        0.             10.5                        14.»
8

Parameters yield(c) crop yield (tons per hectare) /
                    rice  = 2.0, maize = 2.0,  cassava1 = 13.0, cassava2 = 13»
.0
                    beans = 1.0, banana = 9.6 , citrus  = 7.3, jatropha = 5.5»
    /
```

---

[114] * (5.5 t/ha; US$ 140/t)

```

           price(c) crop prices (dollars per ton)             /
                    rice  = 130, maize  = 111,  cassava1 = 46, cassava2 = 46
                    beans = 435, banana  =  56,  citrus = 111, jatropha = 140»
 /

           miscost(c) misc cash costs (dollars per hectare)   /
           jatropha = 182 /;

* farm and labour data:

Scalars land    farm size (hectares)                       /  9.4  /
        famlab  family labor available (days per month)    / 63   /
        twage   temporary labor wage  (dollars per day)    /  5  /
        fwage   family labor wage                          / 4 /


$Stitle endogenous variables and equations

Variables  xcrop(c)   cropping activity         (hectares)
           yfarm      farm income               (dollars)
           revenue    value of production       (dollars)
           labcost    labor cost                (dollars)
           flab(t)    family labor use          (days)
           tlab(t)    temporary labor           (days)

Positive Variable xcrop, flab ,fout, tlab

Equations  landbal(t)   land balance              (hectares)
           laborbal(t)  labor balance             (days)
           flabor(t)    family labor balance      (days)
           arev         revenue accounting        (dollars)
           alab         labor cost accounting     (dollars)
           income       income definition         (dollars)
           landprep(t)  landpreparation demand    (hectares)
           cycle1       rice-plantain-plantain    (hectares)
           cycle2       maize-cassava1-cassava1   (hectares)
           cycle3       beans-cassava2-cassava2   (hectares);

landbal(t)..   sum(c, xcrop(c))  =l= land             ;

laborbal(t)..  sum(c, xcrop(c)*laborreq(t,c)) =l= flab(t) + tlab(t);

flabor(t)..    flab(t) =l= famlab                        ;

arev..         revenue =e= sum(c, xcrop(c)*yield(c)*price(c))      ;

alab..         labcost =e= sum(t, tlab(t)*twage) + sum(t, flab(t)*fwage) ;

income..       yfarm   =e= revenue - labcost                                      »
            ;

landprep(t)..  xcrop("falland") =g= sum(d, xcrop(d)) ;

cycle1..       2*xcrop("rice") =e= xcrop("banana");

cycle2..       2*xcrop("maize") =e= xcrop("cassava1");

cycle3..       2*xcrop("beans") =e= xcrop("cassava2");


```

```
Model demo1 farm labor model / all /;

xcrop.LO("cassava1") = 0.5;
xcrop.LO("cassava2") = 0.2;
xcrop.LO("maize") = 0.25;
xcrop.LO("beans") = 0.1;
xcrop.LO("banana") = 1;
xcrop.LO("rice") = 0.5;
xcrop.UP("citrus") = 0.42;
tlab.UP(t) = 0.;

Solve demo1 using lp maximizing yfarm ;

Sets crep    / landuse, output, revenue, profit, profitpc, profitclear /
     lrep    / demand,  family, temporary
               unused /
     cycrep  /cyc1profitclear,cyc2profitclear,cyc3profitclear,
                 cyc1profitpc, cyc2profitpc, cyc3profitpc,
                 cyc1landuse, cyc2landuse, cyc3landuse  /

Parameters  croprep crop report summary
            labrep  labor report summary(days)
           cyclerep    cycle report summary;

croprep("landuse",c)  = xcrop.l(c);
croprep("output",c)   = xcrop.l(c)*yield(c);
croprep("revenue",c)  = croprep("output",c)*price(c);
croprep("profit",c)   = croprep("revenue",c)- xcrop.l(c) * sum(t,laborreq(t,c»
)) * fwage ;
alias(c,cc);
croprep("profitpc",d) = (croprep("profit",d) - xcrop.l(d) * 21 * fwage) * 100»
 / sum(cc, croprep("profit",cc));
alias(c,ccc);
croprep("profitpc",p) = croprep("profit",p) * 100 / (sum(ccc, croprep("profit»
",ccc)));
alias(c,cccc);
croprep("profitclear",d)   = croprep("profitpc",d) * (sum(cccc, croprep("prof»
it",cccc))) / 100 ;
croprep("profitclear",p)   = croprep("profit",p) ;
croprep(crep,"total") = sum(c, croprep(crep,c));

labrep(t,"demand")    = sum(c, xcrop.l(c)*laborreq(t,c));
labrep(t,"family")    = flab.l(t);
labrep(t,"temporary") = tlab.l(t);
labrep(t,"unused")    = -laborbal.l(t);
labrep("total",lrep)  = sum(t, labrep(t,lrep));


cyclerep("cyc1profitclear",a) = croprep("profitclear",a) ;
cyclerep("cyc2profitclear",b)  = croprep("profitclear",b) ;
cyclerep("cyc3profitclear",f)  = croprep("profitclear",f) ;

cyclerep("cyc1profitpc",a)  = croprep("profitpc",a) ;
cyclerep("cyc2profitpc",b)  = croprep("profitpc",b) ;
cyclerep("cyc3profitpc",f)  = croprep("profitpc",f) ;

cyclerep("cyc1landuse",a)  = croprep("landuse",a) ;
cyclerep("cyc2landuse",b)  = croprep("landuse",b) ;
cyclerep("cyc3landuse",f)  = croprep("landuse",f) ;

cyclerep(cycrep,"total") = sum(cc, cyclerep(cycrep,cc));
```

```
Display "landuse      [ha]"
        "output       [t] "
        "revenue      [$] "
        "profit       [$] "
        "profitpc     [%] "
        "profitclear  [$] ", croprep, labrep, cyclerep;
display tlab.l  ;
```

Code VIII: Scenario c – Subcase 3[115]

```
$Title Farm Level Model San Martín, Peru (DEMO1,SEQ=91)
*$Stitle Crop Data

$Ontext

GAMS model for assessing the profitability of jatropha (scenario c - subcase »
3)


David van der Zaan


$Offtext


Sets  c crops   / rice, maize, cassava1,cassava2, beans,
                   banana, citrus, falland, jatropha  /

      d(c) dcrops / rice, maize, cassava1, cassava2,
                          beans, banana /

      p(c) pcrops / citrus, jatropha /

      a(c) acrops / rice, banana /

      b(c) bcrops / maize, cassava1 /

      f(c) ccrops / beans, cassava2 /

      t period  / jan, feb, mar, apr, may, jun,
                  jul, aug, sep, oct, nov, dec  /

Table laborreq(t,c) crop and fallow land labor requirements (man-days per hec»
tare)

     rice   maize  cassava1 cassava2  beans  banana  citrus   falland   jatro»
pha
jan   25.    16.    10.       10.             10.                         10.»
2
feb                  0.        0.      14.    12.                         11.»
4
mar                  0.        0.      20.     0.     15.                 15.»
3
apr                 10.       10.       0.     0.     30.5                12.»
1
may                  0.        0.      10.    12.     30.5                8
jun                  0.        0.      30.     0.     30.5                8
jul                 21.       21.              0.     30.5      10        3.4
aug                 21.       21.             12.               11        0.
sep   10.   10.                               10.5                        4.7
oct   10.   10.                               10.5                        11.»
4
nov   10.    0.      4.        4.             10.5                        15.»
3
dec    0.    0.      0.        0.             10.5                        12.»
1

Parameters yield(c) crop yield (tons per hectare) /
                    rice  = 2.0, maize = 2.0,  cassava1 = 13.0, cassava2 = 13»
.0
                    beans = 1.0, banana = 9.6 , citrus  = 7.3, jatropha = 3.7»
```

---

[115] * (3.7 t/ha; US$ 180/t)

```
    /

           price(c) crop prices (dollars per ton)             /
                    rice  = 130, maize  = 111,  cassava1 = 46, cassava2 = 46
                    beans = 435, banana  =  56,  citrus = 111, jatropha = 180»
 /

           miscost(c) misc cash costs (dollars per hectare)   /
           jatropha = 182 /;

* farm and labour data:

Scalars land    farm size (hectares)                         /  9.4  /
        famlab  family labor available (days per month)      / 63   /
        twage   temporary labor wage  (dollars per day)      /  5  /
        fwage   family labor wage                            / 4 /


$Stitle endogenous variables and equations

Variables  xcrop(c)   cropping activity         (hectares)
           yfarm      farm income               (dollars)
           revenue    value of production       (dollars)
           labcost    labor cost                (dollars)
           flab(t)    family labor use          (days)
           tlab(t)    temporary labor           (days)

Positive Variable xcrop, flab ,fout, tlab

Equations  landbal(t)   land balance              (hectares)
           laborbal(t)  labor balance             (days)
           flabor(t)    family labor balance      (days)
           arev         revenue accounting        (dollars)
           alab         labor cost accounting     (dollars)
           income       income definition         (dollars)
           landprep(t)  landpreparation demand    (hectares)
           cycle1       rice-plantain-plantain    (hectares)
           cycle2       maize-cassava1-cassava1   (hectares)
           cycle3       beans-cassava2-cassava2   (hectares);

landbal(t)..   sum(c, xcrop(c))  =l= land             ;

laborbal(t)..  sum(c, xcrop(c)*laborreq(t,c)) =l= flab(t) + tlab(t);

flabor(t)..    flab(t) =l= famlab                       ;

arev..         revenue =e= sum(c, xcrop(c)*yield(c)*price(c))      ;

alab..         labcost =e= sum(t, tlab(t)*twage) + sum(t, flab(t)*fwage) ;

income..       yfarm   =e= revenue - labcost                                »
            ;

landprep(t)..  xcrop("falland") =g= sum(d, xcrop(d)) ;

cycle1..       2*xcrop("rice") =e= xcrop("banana");

cycle2..       2*xcrop("maize") =e= xcrop("cassava1");

cycle3..       2*xcrop("beans") =e= xcrop("cassava2");

```

```

Model demo1 farm labor model / all /;

xcrop.LO("cassava1") = 0.5;
xcrop.LO("cassava2") = 0.2;
xcrop.LO("maize") = 0.25;
xcrop.LO("beans") = 0.1;
xcrop.LO("banana") = 1;
xcrop.LO("rice") = 0.5;
xcrop.UP("citrus") = 0.42;
tlab.UP(t) = 0.;

Solve demo1 using lp maximizing yfarm ;

Sets crep    / landuse, output, revenue, profit, profitpc, profitclear /
     lrep    / demand,  family, temporary
               unused /
     cycrep  /cyc1profitclear,cyc2profitclear,cyc3profitclear,
                 cyc1profitpc, cyc2profitpc, cyc3profitpc,
                 cyc1landuse, cyc2landuse, cyc3landuse  /

Parameters  croprep crop report summary
            labrep  labor report summary(days)
           cyclerep    cycle report summary;

croprep("landuse",c)  = xcrop.l(c);
croprep("output",c)   = xcrop.l(c)*yield(c);
croprep("revenue",c)  = croprep("output",c)*price(c);
croprep("profit",c)   = croprep("revenue",c)- xcrop.l(c) * sum(t,laborreq(t,c»
))  * fwage ;
alias(c,cc);
croprep("profitpc",d) = (croprep("profit",d) - xcrop.l(d) * 21 * fwage) * 100»
 / sum(cc, croprep("profit",cc));
alias(c,ccc);
croprep("profitpc",p) = croprep("profit",p) * 100 / (sum(ccc, croprep("profit»
",ccc)));
alias(c,cccc);
croprep("profitclear",d)   = croprep("profitpc",d) * (sum(cccc, croprep("prof»
it",cccc))) / 100 ;
croprep("profitclear",p)   = croprep("profit",p) ;
croprep(crep,"total") = sum(c, croprep(crep,c));

labrep(t,"demand")    = sum(c, xcrop.l(c)*laborreq(t,c));
labrep(t,"family")    = flab.l(t);
labrep(t,"temporary") = tlab.l(t);
labrep(t,"unused")    = -laborbal.l(t);
labrep("total",lrep)  = sum(t, labrep(t,lrep));


cyclerep("cyc1profitclear",a) = croprep("profitclear",a) ;
cyclerep("cyc2profitclear",b)  = croprep("profitclear",b) ;
cyclerep("cyc3profitclear",f)  = croprep("profitclear",f) ;

cyclerep("cyc1profitpc",a)  = croprep("profitpc",a) ;
cyclerep("cyc2profitpc",b)  = croprep("profitpc",b) ;
cyclerep("cyc3profitpc",f)  = croprep("profitpc",f) ;

cyclerep("cyc1landuse",a)  = croprep("landuse",a) ;
cyclerep("cyc2landuse",b)  = croprep("landuse",b) ;
cyclerep("cyc3landuse",f)  = croprep("landuse",f) ;

```

```
cyclerep(cycrep,"total") = sum(cc, cyclerep(cycrep,cc));


Display "landuse      [ha]"
        "output       [t] "
        "revenue      [$] "
        "profit       [$] "
        "profitpc     [%] "
        "profitclear  [$] ", croprep, labrep, cyclerep;
display tlab.l  ;
```

Code IX: Scenario c – Subcase 4[116]

```
$Title Farm Level Model San Martín, Peru (DEMO1,SEQ=91)
*$Stitle Crop Data

$Ontext

GAMS model for assessing the profitability of jatropha (scenario c - subcase »
4)


David van der Zaan


$Offtext


Sets  c crops   / rice, maize, cassava1,cassava2, beans,
                   banana, citrus, falland, jatropha  /

      d(c) dcrops / rice, maize, cassava1, cassava2,
                          beans, banana /

      p(c) pcrops / citrus, jatropha /

      a(c) acrops / rice, banana /

      b(c) bcrops / maize, cassava1 /

      f(c) ccrops / beans, cassava2 /

      t period  / jan, feb, mar, apr, may, jun,
                  jul, aug, sep, oct, nov, dec  /

Table laborreq(t,c) crop and fallow land labor requirements (man-days per hec»
tare)

     rice   maize  cassava1 cassava2  beans  banana  citrus   falland   jatro»
pha
jan   25.    16.    10.       10.            10.                          10.»
2
feb                  0.        0.      14.   12.                          11.»
4
mar                  0.        0.      20.    0.     15.                  15.»
3
apr                 10.       10.       0.    0.     30.5                 12.»
1
may                  0.        0.      10.   12.     30.5                 8
jun                  0.        0.      30.    0.     30.5                 8
jul                 21.       21.             0.     30.5      10         3.4
aug                 21.       21.            12.               11         0.
sep   10.   10.                              10.5                         4.7
oct   10.   10.                              10.5                         11.»
4
nov   10.    0.      4.        4.            10.5                         15.»
3
dec    0.    0.      0.        0.            10.5                         12.»
1

Parameters yield(c) crop yield (tons per hectare) /
                    rice  = 2.0, maize = 2.0,  cassava1 = 13.0, cassava2 = 13»
.0
                    beans = 1.0, banana = 9.6 , citrus  = 7.3, jatropha = 3.7»
```

---

[116] * (3.7 t/ha; US$ 140/t)

```
    /

           price(c) crop prices (dollars per ton)             /
                    rice  = 130, maize  = 111,  cassava1 = 46, cassava2 = 46
                    beans = 435, banana  =  56,  citrus = 111, jatropha = 140»
 /

           miscost(c) misc cash costs (dollars per hectare)   /
           jatropha = 182 /;

* farm and labour data:

Scalars land    farm size (hectares)                       /  9.4  /
        famlab  family labor available (days per month)    / 63   /
        twage   temporary labor wage  (dollars per day)    /  5  /
        fwage   family labor wage                          / 4 /


$Stitle endogenous variables and equations

Variables  xcrop(c)   cropping activity         (hectares)
           yfarm      farm income               (dollars)
           revenue    value of production       (dollars)
           labcost    labor cost                (dollars)
           flab(t)    family labor use          (days)
           tlab(t)    temporary labor           (days)

Positive Variable xcrop, flab ,fout, tlab

Equations  landbal(t)   land balance              (hectares)
           laborbal(t)  labor balance             (days)
           flabor(t)    family labor balance      (days)
           arev         revenue accounting        (dollars)
           alab         labor cost accounting     (dollars)
           income       income definition         (dollars)
           landprep(t)  landpreparation demand    (hectares)
           cycle1       rice-plantain-plantain    (hectares)
           cycle2       maize-cassava1-cassava1   (hectares)
           cycle3       beans-cassava2-cassava2   (hectares);

landbal(t)..   sum(c, xcrop(c))  =l= land             ;

laborbal(t)..  sum(c, xcrop(c)*laborreq(t,c)) =l= flab(t) + tlab(t);

flabor(t)..    flab(t) =l= famlab                        ;

arev..         revenue =e= sum(c, xcrop(c)*yield(c)*price(c))      ;

alab..         labcost =e= sum(t, tlab(t)*twage) + sum(t, flab(t)*fwage) ;

income..       yfarm   =e= revenue - labcost                              »
            ;

landprep(t)..  xcrop("falland") =g= sum(d, xcrop(d)) ;

cycle1..       2*xcrop("rice") =e= xcrop("banana");

cycle2..       2*xcrop("maize") =e= xcrop("cassava1");

cycle3..       2*xcrop("beans") =e= xcrop("cassava2");

```

```

Model demo1 farm labor model / all /;

xcrop.LO("cassava1") = 0.5;
xcrop.LO("cassava2") = 0.2;
xcrop.LO("maize") = 0.25;
xcrop.LO("beans") = 0.1;
xcrop.LO("banana") = 1;
xcrop.LO("rice") = 0.5;
xcrop.UP("citrus") = 0.42;
tlab.UP(t) = 0.;

Solve demo1 using lp maximizing yfarm ;

Sets crep    / landuse, output, revenue, profit, profitpc, profitclear /
     lrep    / demand,  family, temporary
               unused /
     cycrep  /cyc1profitclear,cyc2profitclear,cyc3profitclear,
                 cyc1profitpc, cyc2profitpc, cyc3profitpc,
                 cyc1landuse, cyc2landuse, cyc3landuse  /

Parameters  croprep crop report summary
            labrep  labor report summary(days)
           cyclerep    cycle report summary;

croprep("landuse",c)  = xcrop.l(c);
croprep("output",c)   = xcrop.l(c)*yield(c);
croprep("revenue",c)  = croprep("output",c)*price(c);
croprep("profit",c)   = croprep("revenue",c)- xcrop.l(c) * sum(t,laborreq(t,c»
)) * fwage ;
alias(c,cc);
croprep("profitpc",d) = (croprep("profit",d) - xcrop.l(d) * 21 * fwage) * 100»
 / sum(cc, croprep("profit",cc));
alias(c,ccc);
croprep("profitpc",p) = croprep("profit",p) * 100 / (sum(ccc, croprep("profit»
",ccc)));
alias(c,cccc);
croprep("profitclear",d)   = croprep("profitpc",d) * (sum(cccc, croprep("prof»
it",cccc))) / 100 ;
croprep("profitclear",p)   = croprep("profit",p) ;
croprep(crep,"total") = sum(c, croprep(crep,c));

labrep(t,"demand")    = sum(c, xcrop.l(c)*laborreq(t,c));
labrep(t,"family")    = flab.l(t);
labrep(t,"temporary") = tlab.l(t);
labrep(t,"unused")    = -laborbal.l(t);
labrep("total",lrep)  = sum(t, labrep(t,lrep));


cyclerep("cyc1profitclear",a) = croprep("profitclear",a) ;
cyclerep("cyc2profitclear",b)  = croprep("profitclear",b) ;
cyclerep("cyc3profitclear",f)  = croprep("profitclear",f) ;

cyclerep("cyc1profitpc",a)  = croprep("profitpc",a) ;
cyclerep("cyc2profitpc",b)  = croprep("profitpc",b) ;
cyclerep("cyc3profitpc",f)  = croprep("profitpc",f) ;

cyclerep("cyc1landuse",a)  = croprep("landuse",a) ;
cyclerep("cyc2landuse",b)  = croprep("landuse",b) ;
cyclerep("cyc3landuse",f)  = croprep("landuse",f) ;

```

```
cyclerep(cycrep,"total") = sum(cc, cyclerep(cycrep,cc));


Display "landuse      [ha]"
        "output       [t] "
        "revenue      [$] "
        "profit       [$] "
        "profitpc     [%] "
        "profitclear  [$] ", croprep, labrep, cyclerep;
display tlab.l  ;
```

Erklärung

Hiermit versichere ich, dass ich die vorliegende Arbeit selbstständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe, dass alle Stellen der Arbeit, die wörtlich oder sinngemäß aus anderen Quellen übernommen wurden, als solche kenntlich gemacht und dass die Arbeit in gleicher oder ähnlicher Form noch keiner Prüfungsbehörde vorgelegt wurde.

Hannover, den 17. April 2008