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# Trading biomass or GHG emission credits?

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**Abstract** Global biomass potentials are considerable but unequally distributed over the world. Countries with Kyoto targets could import biomass to substitute for fossil fuels or invest in bio-energy projects in the country of biomass origin and buy the credits (Clean Development Mechanism (CDM) and Joint Implementation (JI)). This study analyzes which of those options is optimal for transportation fuels and looks for the key variables that influence the result. In two case studies (Mozambique and Brazil), the two trading systems are compared for the amount of credits generated, land-use and associated costs. We found costs of 17–30 euro per ton of carbon for the Brazilian case and economic benefits of 11 to 60 euros per ton of carbon avoided in the Mozambique case. The impact of carbon changes related to direct land-use changes was found to be very significant (both positive and negative) and can currently only be included in emission credit trading, which can largely influence the results. In order to avoid indirect land-use changes (leakage) and consequent GHG emissions, it is crucial that bioenergy crop production is done in balance with improvements of management of agriculture and livestock management. Whatever trading option is economically most attractive depends mainly on the emission baseline in the exporting (emission credit trading) or importing (physical trading) country since both bio- and fossil fuel prices are world market prices in large scale trading systems where transportation costs are low. Physical trading could be preferential since besides the GHG reduction one could also benefit from the energy. It could also generate considerable income sources for exporting countries. This study could contribute to the development of a methodology to deal with bio fuels for transport, in Emission Trading (ET), CDM and the certification of traded bio fuels.

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## 1 Introduction

All countries that ratified The Kyoto Protocol, committed themselves to specific targets to reduce GHG levels.[1] Participating countries can reduce emissions within their country borders. However, apart from this so-called 'domestic action' also some flexible mechanisms were designed that enable participating countries to cooperate with other countries, to enhance cost-effectiveness of climate change mitigation e.g. Joint Implementation (JI) and Clean Development Mechanism (CDM).

Biomass can play an important and dual role in greenhouse gas mitigation: it can be used as an energy source to substitute for fossil fuels, or as a carbon reservoir. Several studies have analyzed the potential contribution of bio-energy to the future world's energy supply (e.g. Smeets et al. 2007; Hoogwijk et al. 2003; Berndes et al. 2002; Hoogwijk et al. 2005). Substantial variation in the estimates of the biomass production potentials exists within and between different studies; ranges are mostly in between 200 and 1200 EJ/year in 2050, of which the forestry biomass potential is now assessed at 12–74 EJ/year (IPCC 2007). Despite the variation in potential, considering the current global energy use of around 400 EJ/year, these studies indicate that the contribution of bio-energy to the future world's energy supply could be very significant. Worldwide biomass potentials are, however, unequally distributed over the world; a large potential biomass production capacity can be found in developing countries and regions such as Latin America, Sub-Saharan Africa and Eastern Europe (Smeets et al. 2007). Countries in these areas can use the biomass within their borders to substitute for fossil fuels; they can, however, also become suppliers of biomass to other countries. This creates important future opportunities for such regions as the export of biomass can generate considerable income sources for the relatively poor regions of the world with large biomass potentials. Countries that have an emission reduction obligation under the Kyoto Protocol can import the biomass/bio-fuels to substitute for fossil fuels (see also a study by Damen and Faaij 2006). In this case, the importing country reduces GHG-emissions by avoiding the use of fossil fuels. The GHG mitigation potential is thus affected by the carbon intensity of the energy system in the importing country (the reference system).

Another option is to convert the biomass locally; by investing in renewable energy projects in these countries, Annex I countries can acquire GHG-emissions credits, which help them reach their targets. The host countries can also benefit from these projects, as the introduction of modern biomass conversion technologies can enable communities to be self-sufficient and reduce the dependency of fossil fuel imports (Hall and House 1994).

Physical trade of biomass/bio-fuels and the trade of emission-credits derived from bio-energy projects (JI and CDM) are thus two options to reduce $CO_2$-eq levels by using biomass. Which of those options is optimal from a land-use, cost and a GHG mitigation perspective will depend on various crucial criteria and will probably differ under different circumstances. In their paper "Should we trade biomass, electricity, renewable certificates or $CO_2$-credits?" members of IEA Task Groups 38 and 40 already briefly discussed different trading options and the dependency upon the

[1]Together, these targets amount to a reduction, in the period of 2008–2012, of at least 5% from 1990 levels (UNFCCC 1997).

specific situations of the "exporting" and "importing" country (Schlamadinger et al. 2004). In this study, we will compare bio-transportation-fuel (biofuel) production in different countries to reveal some regional differences in the production of biomass and its further treatment. Biofuels are also interesting because to date no CDM methodology has been approved for transportation fuels, except for a methodology on the production of biodiesel based on waste oils and/or waste fats from biogenic origin (UNFCCC 2007). The rules and regulations for accounting carbon balances of JI projects, CDM projects and trading of bio-fuels are different and we will investigate the impact of these differences. Induced land-use changes (leakage) are a central and crucial point in the current debate around the net GHG impact of bio-fuels (Fargione et al. 2008; Searchinger et al. 2008). Moreover, other issues like diversification and flexibility may influence the decision for a trading system in both exporting and importing country. Summarizing, the aim of this study is as follows: given the large global bio-energy production potential, how should we make optimal use of this renewable source, regarding, amongst others, land-use, costs and avoided emissions?

In Section 2, for both trading systems a methodological framework is composed, where all factors, accounting methods and legislation influencing the amount and costs of $CO_2$ reduction are represented. In Section 3, two case studies are presented: Mozambique and Brazil. In both case studies, physical trading and emission credit trading are compared for the amount of credits generated, the amount of land-use and the associated costs. Section 4 provides a discussion of the key findings, followed by conclusions and recommendations in Section 5.

## 2 Methodology

For both trading systems, all factors influencing the costs of $CO_2$-reduction need to be recognized and are represented in a methodological framework that will be the basis of study.

### 2.1 Physical biomass trade

For physical biomass trade (Fig. 1), the chain starts with biomass production and harvesting in the exporting country. Depending on the form in which it is transported, different pre-treatment options are needed. Storage and transportation might occur in both exporting and importing country and international transport occurs between those countries. Finally, the biomass is converted in the importing country. The total amount of GHG-emissions and costs for this chain can be calculated by adding them for all steps in the logistic chain. To determine the costs and amount of GHG-emission reduction, the chain needs to be compared with the total costs and GHG-emissions of the reference energy system of the importing country. In the case of residual biomass, emission and costs related to biomass production and harvesting need to be allocated for residues, moreover, they need to be compared with the residue reference system (the use of residues if not used for energy generation). Since the conversion efficiencies of biomass and fossil fuels might be different, the systems need to be compared based on the same amount of final energy produced. In the case of dedicated crops, there might also be a sequestration component to account for. If

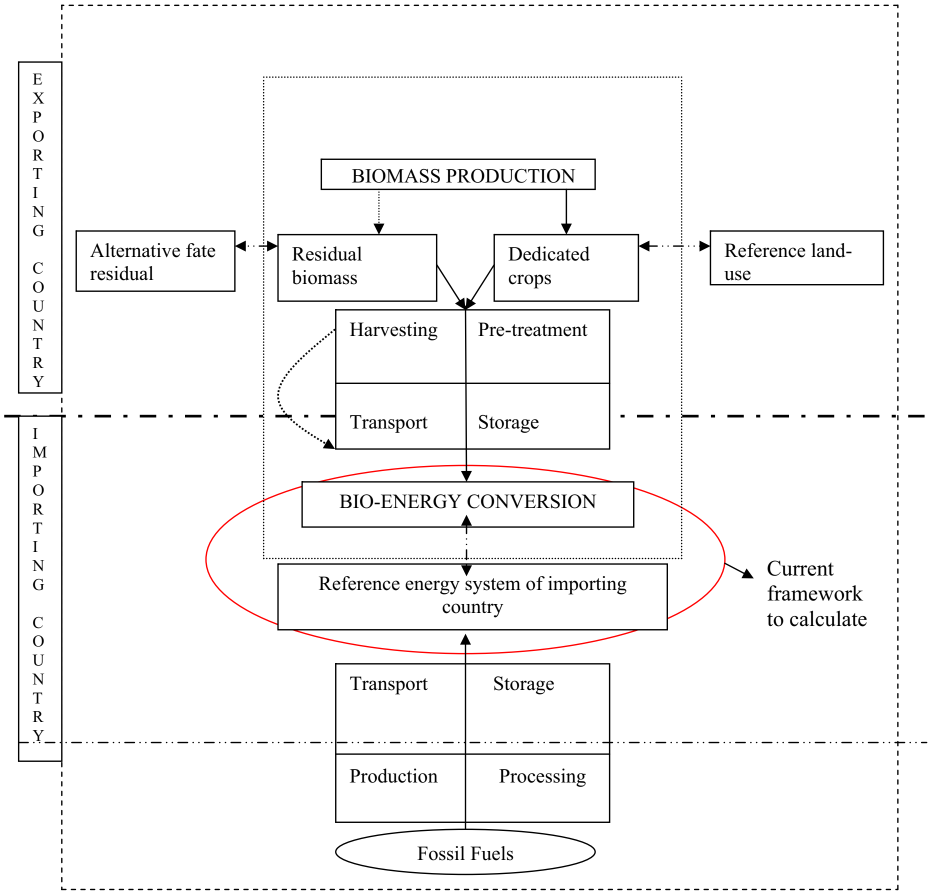


**Fig. 1** Methodological framework for physical biomass trade

the exporting country is an Annex I country, they can include this sequestration in their National GHG Inventory (net-net or gross-net accounting approach, depending on the type of activity IPCC 2003).[2] If the exporting country is a non-Annex I country, sequestration is not accounted for since there are no National Inventory and Kyoto targets to comply with. More worrying is if the biomass production leads to a net carbon loss, e.g. due to unsustainable harvesting in existing forests, there is, so far, no mechanism to account for this loss.

Currently, in e.g. the Netherlands, the avoided GHG-emissions by using bio energy are calculated by assuming that biomass has, by default, zero emissions. Upstream emissions for both biomass and fossil fuels chains are ignored (or assumed to be equivalent). The amount of emission reduction is calculated only by determining the amount of avoided emissions during conversion of the reference fuel. Thus, also

[2]The sequestration benefit lies, however, with the exporter and it would probably (in reality) not affect the costs of GHG-emission for the importing country.

the emissions (or reductions) related to reference land-use and the alternative fates of residues are ignored.

For the purpose of this study, two options to determine the costs of GHG-emission reduction for physical biomass trade will be explored:

1) The amount of emission reduction is determined by calculating the amount of GHG-emission during conversion of the avoided fossil fuels only. The associated costs, are the differences in the costs of the biomass chain and the fossil fuel chain.

$$C_{\text{avoidance}} = \frac{C_{\text{B}} - C_{\text{R}}}{E_{\text{R}}} \tag{1}$$

where:

| | |
|---|---|
| $C_{\text{avoidance}}$ | Costs per avoided GHG emission (€/$CO_2$-eq) |
| $E_{\text{R}}$ | GHG emissions for reference (fossil fuel) chain, excluding up-stream emissions ($CO_2$-eq) |
| $C_{\text{B}}$ | Costs for biomass chain (€) |
| $C_{\text{R}}$ | Costs for reference (fossil fuels) chain (€) |

2) To determine the "real" emission reductions in the physical biomass trading system, in the second scenario, all factors as represented in Fig. 6 will be included. In this scenario, the costs of the avoided emissions for physical biomass trading can be calculated as follows:

$$C_{\text{avoidance}} = \frac{C_{\text{B}} - C_{\text{R}} + / - C_{\text{A}}}{E_{\text{R}} - E_{\text{B}} + / - E_{\text{A}} + / - E_{\text{L}} + / - E_{\text{K}}} \tag{2}$$

where:

| | |
|---|---|
| $C_{\text{avoidance}}$ | Costs per avoided GHG emission (€/$CO_2$-eq) |
| $C_{\text{B}}$ | Costs for biomass chain (€) |
| $C_{\text{R}}$ | Costs for reference chain (€) |
| $C_{\text{A}}$ | Costs/benefits related to alternative use of residues (€) |
| $E_{\text{R}}$ | GHG emissions for reference (fossil fuel) chain ($CO_2$-eq) |
| $E_{\text{B}}$ | GHG emissions for biomass chain ($CO_2$-eq) |
| $E_{\text{A}}$ | Emissions (benefits) related to alternative fate of residues ($CO_2$-eq) |
| $E_{\text{L}}$ | Carbon gains or losses compared to reference land-use ($CO_2$-eq)[3] |
| $E_{\text{K}}$ | Emissions (benefits) due to leakage ($CO_2$-eq) |

[3]Note: the costs or benefits (€) that occur due to carbon losses or carbon sequestration are not directly included in the model as they will be reflected in the final costs of $CO_2$ avoidance. If there is for example a net sequestration effect, the amount of avoided carbon will increase, resulting in lower costs of $CO_2$ avoidance for the whole chain.

2.2 Emission credit trade

For emission credit trade, the core part of the methodological framework (Fig. 2) is the same as for physical biomass trade, only the whole chain occurs in the exporting country. Two types of baselines can emerge for bio-energy projects:

A) The GHG emission baseline. In general this baseline represents: "the anthropogenic emissions by sources that would occur in the absence of the proposed project activity".

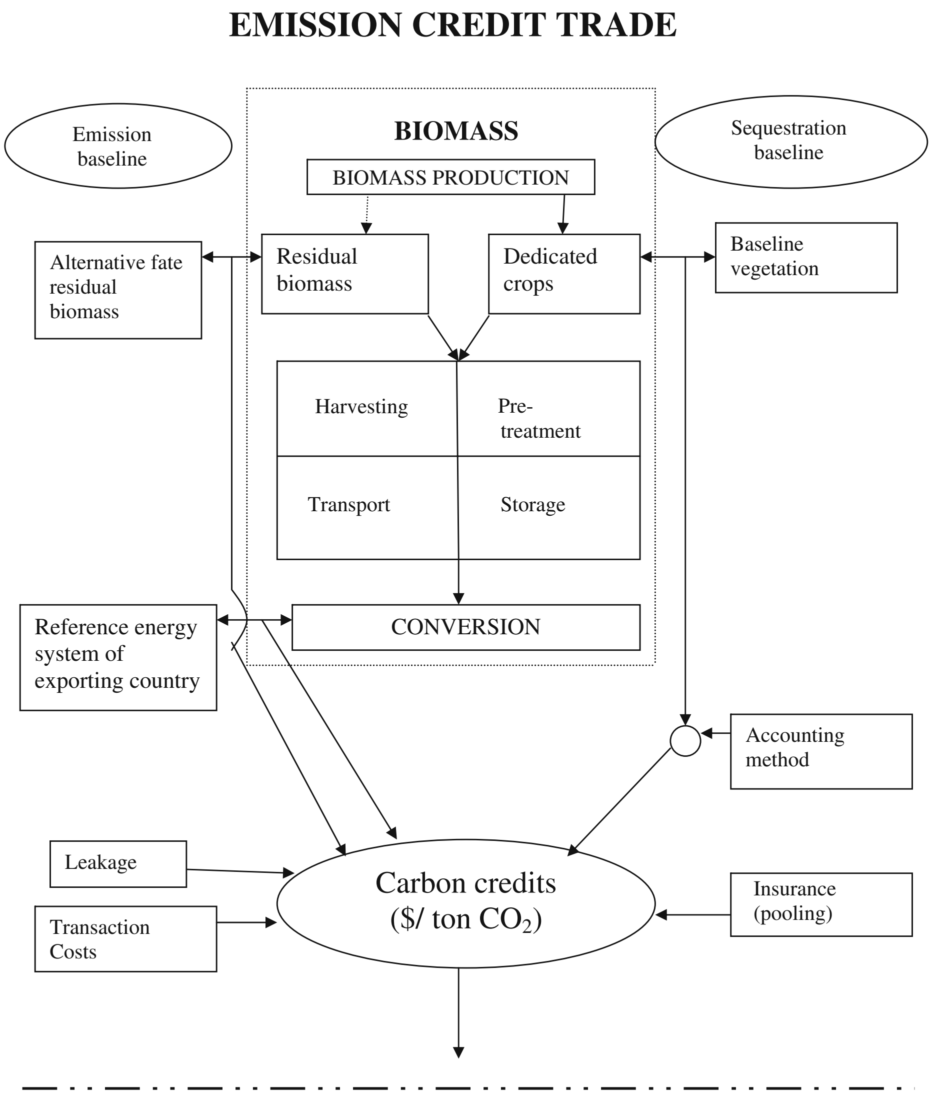


**Fig. 2** Methodological framework for emission credit trade

B) The sequestration baseline: to consider carbon stock changes associated with biomass production.

The biomass project might thus be split up in two parts: a fuel-switch project (A) and a sequestration project (B) (the contribution of (B) can be very significant to the total amount of carbon mitigated (Schlamadinger et al. 2001)). For sequestration projects, a distinction should be made between JI and CDM projects. Firstly, because the range of eligible land-use, land-use change and forestry (LULUCF) activities under the CDM is limited to afforestation and reforestation, while for JI all LULUCF activities are eligible. Secondly, because of the non-permanence risk (i.e. fire, diseases, harvesting etc.) related to sequestration projects. The threat associated with this non-permanence issue is that credits are issued for carbon sequestration while the carbon is lost and the credits cannot be taken back. The issue of permanence in LULUCF projects does not arise for JI projects because they are implemented in Annex I countries with established national GHG inventories. For LULUCF sector reporting by Annex I countries, it has been agreed under the Kyoto Protocol that the "Stock Change" (SC) approach will be used.[4] For CDM projects, on the other hand, the non-permanence issue plays a large role since there is no mechanism to compensate for reductions in carbon stocks. This complex and highly debated issue in the negotiations towards the implementation of the Kyoto Protocol, leaded to various proposals of accounting methods to address this issue. The accounting method to be applied for A/R projects in the CDM for the first commitment period (Temporary Crediting) was ultimately decided upon at COP 9 in Milan. In this study, four accounting methods (Stock Change, Average Storage, Ton Year and Temporary Crediting) will be modelled in order to determine the effect of different approaches on the costs of GHG-emission reduction.

When the project is implemented and monitored, credits, resulting from the project activity, can be calculated and should be adjusted for leakage (UNFCCC 2001). Apart from the direct investment and operation & maintenance costs that come with the implementation of bio energy projects, CDM and JI projects lead to extra transaction cost. Transaction costs for CDM projects can be divided in market, pre-implementation and implementation transaction costs that arise from the CDM project cycle (Krey 2004). For JI projects, transaction costs vary depending on which "track" is applied. In the Track 1 procedure, the project design, the project performance and emission reduction calculations do not need to be validated, monitored and verified by an entity officially designated by the UNFCCC or the COP; this will reduce the transaction costs. The Track 2 procedure is very similar to the CDM project cycle.

With the implementation of projects, there is always the risk of failure and consequently, the inability to generate the foreseen credits. There are various ways to reduce this risk, one often seen example is the bundling of many (smaller) projects into a pool of projects. Although this will generate extra costs, it can also be beneficial in terms of transaction costs. Transaction costs are especially high for small-scale projects, and by bundling several smaller project into a pool, the costs of some

[4]Guidelines on this approach are described in the Good Practice Guidance for LULUCF (IPCC 2003).

(fixed) components of the transaction can be divided among different projects.[5] Another way of reducing the risk of non-delivery on a project-by-project base is that sellers reserve a certain percentage (approx. 20%) of the credits from each year's production into a non-delivery buffer. Whatever type of insurance is selected, it will always bring along extra cost, which should be included when calculating the cost of emission reduction in the emission credit trade system.

The costs of GHG-reduction for emission credit trade can now be calculated as follows:

$$C_{\text{avoidance}} = \frac{C_B + C_T - C_R}{E_R - E_B +/- E_L +/- E_K - E_I} \tag{3}$$

where:

| | |
|---|---|
| $C_{\text{avoidance}}$ | Costs per avoided GHG emission (€/$CO_2$-eq) |
| $C_B$ | Costs for biomass project (I en O&M) (€) |
| $C_T$ | Transaction costs (€) |
| $C_R$ | Costs for (avoided) reference energy (€) |
| $E_R$ | GHG emissions for reference system (=baseline emissions) ($CO_2$-eq) |
| $E_B$ | GHG emissions for biomass chain (=project emissions) ($CO_2$-eq) |
| $E_L$ | Carbon gains or losses compared to reference land-use ($CO_2$-eq) |
| $E_K$ | Emissions (benefits) due to leakage ($CO_2$-eq) |
| $E_I$ | Reduction of carbon credits due to insurance (buffer) ($CO_2$-eq)[6] |

## 3 Case studies

Two case study countries are selected: Mozambique and Brazil. For both countries, two fictional trading systems are analyzed: physical trading of biomass fuels from the country of origin to the Netherlands and the trade of emission credits derived from biofuel projects in the country of biomass origin. Transportation fuels are chosen in both cases since the transportation sector is a large contributor to global GHG-emissions, transportation fuels are easy to trade and there is a large potential for bio-based transportation fuels (Faaij 2006). Data collection is based on existing studies in both cases.

### 3.1 Mozambique

#### *3.1.1 Case description*

In Fig. 3, the considered chains, including the reference systems, are summarised. System 1 represents the physical trading case. This system includes the production and harvesting of eucalyptus in Mozambique. After harvest, the biomass is transported by trucks to a local gathering point where it is converted to pyrolysis oil.

[5]The Executive Board of the CDM, also recognized the large transaction cost burden of small-scale CDM projects, and adopted the simplified CDM rules for small-scale CDM projects (UNFCCC 2002).

[6]We choose here to express the insurance costs in carbon credits, because that is the method applied with buffering. However, it could also be expressed in monetary units.

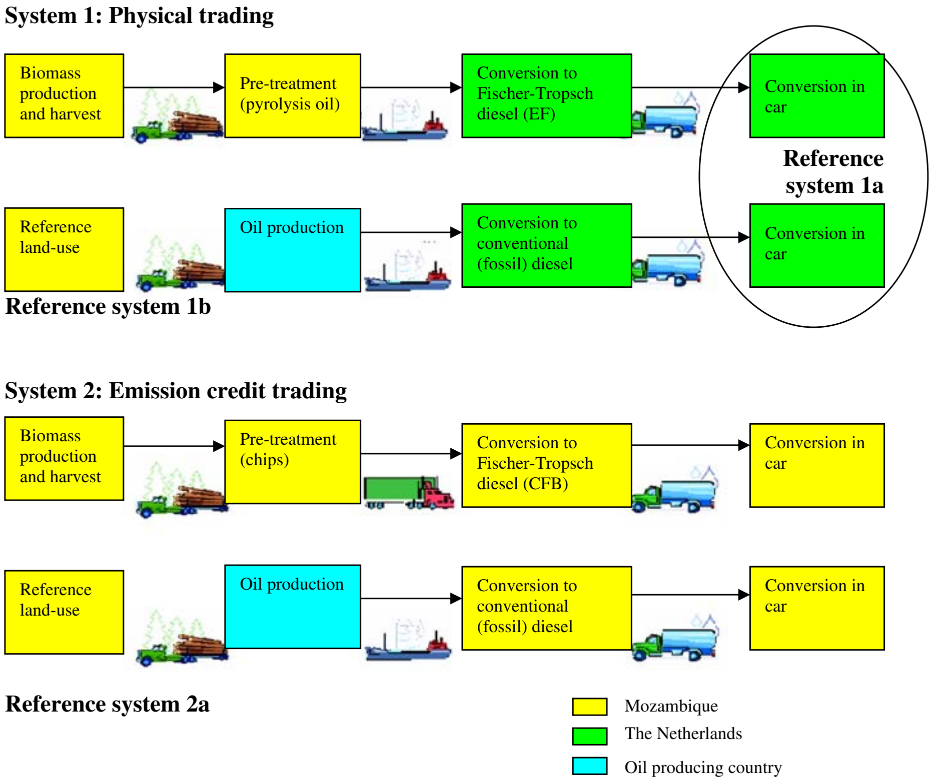


**Fig. 3** Mozambique: biomass trading systems with reference systems

The pyrolysis oil is transported by trucks to the harbour for international shipping. In the Rotterdam Harbour, conversion into Fischer-Tropsch diesel via Entrained Flow gasification (1000 $MW_{th}$) takes place. Finally, the FT-diesel is distributed to the fuel stations where cars are filled, after which the final conversion occurs in the car. The reference fuel is assumed to be (fossil fuel) diesel. Fischer-Tropsch diesel can be used in common Internal Combustion Engines (ICEs) without adaptation and is thus completely interchangeable with fossil fuel diesel. Reference system 1a corresponds to the current calculation method, where emissions and land use changes of both system 1 and the reference system are ignored. Reference system 1b indicates the complete chain.

System 2 represents the emission credit trade case. The system denotes a fictive CDM project in Mozambique where a eucalyptus plantation is established. The harvested wood is transported by trucks to a local gathering point where chips are produced. The chips are transported by trucks to a conversion facility where Fischer-Tropsch diesel is produced via CFB gasification (387 $MW_{th}$). The FT-diesel is finally transported to the fuel stations after which it is converted in the car. Reference system 2a corresponds to the baseline situation in Mozambique.

*Land-use* The debate over 'carbon debt' created by land use changes has currently expanded to include the issue of competition between food and fuel, as the production of biofuels will put additional pressure on land. Recent studies have justly debated that including the greenhouse gas emissions from direct or indirect land clearance could drastically worsen or even revert the greenhouse gas emission balance of growing plants for bio energy (Fargione et al. 2008; Searchinger et al. 2008). Other studies, however, have indicated that it is well possible to avoid leakage due to bio-energy production if, at the same time, the productivity of agriculture and cattle-breeding is improved (Batidzirai et al. 2006; Smeets and Faaij 2008). Presently, the productivity of agriculture in Mozambique is very low compared to what is technically feasible. Batidzirai et al. (2006) showed that around 25 million hectares could be made available for bio-energy production in 2015 when the level of agricultural technology is increased from low to intermediate. In this case study we assume that the land for bio-energy production of dedicated crops is limited to surplus land not required for food production. However, as the leakage effect of bio-energy production is such an important issue it will be taken up further in the discussion.

### *3.1.2 Data*

Data on costs and emissions related to the production, logistics and conversion of the fuels (*fuel switch*) are given in Table 1. Data on carbon sequestration or loss related to the switch in land use (*land use change*) are shown in Table 2. For the CDM case (system 2) data on *transaction costs and risks* are also provided.

*Fuel-switch* For the physical trading system, the fuel costs are composed of the costs to deliver the diesel in Rotterdam (including production, logistic and conversion costs) and costs to deliver the fuel at the fuel stations (distribution costs). The conversion of FT fuels is assumed to be by a new facility that uses the Entrained Flow (EF) gasification technique (1000 $MW_{th}$) and is fed with pyrolysis oil. Emissions can be divided in upstream or well-to-tank (WTT) emissions that occur during the production and transportation of the fuel and tailpipe or tank-to-wheel (TTW) emissions that occur during conversion in the car.

For the emission trading system, we estimate fuel costs and emissions based on the study by Batidzirai et al. (2006). The conversion of FT fuels is assumed to be by a new build plant that uses the Circulating Fluidised Bed (CFB) gasification technique and is fed with chips. The capacity of the conversion facility is assumed to be 387 $MW_{th}$ on an input basis. Batidzirai et al. (2006) calculated fuel costs of 9.1 €/$GJ_{HHV}$ and WWT emissions of 2.5 kg $CO_2/GJ_{HHV}$ for FT-diesel, produced in Mozambique and delivered in the Rotterdam Harbour. Since we assume that the FT-diesel is not transported to the Netherlands but is used in Mozambique itself, the emissions and costs of the international ship transport are subtracted to derive fuel costs and emissions. Reference system 2a represents the production and use of conventional diesel in Mozambique. Most cars in Mozambique are older than current European cars; therefore, the fuel economy of African diesel cars is lower than the fuel economy of current European cars. In the reference case, we assume a direct emission (TTW) of 180 g/km for diesel cars in Mozambique. The assumption is based on several (older) studies (i.e. Little 1999) for cars in Europe. Specific data for Africa could not be found. For the WTT part we assume a value of 26 g $CO_{2eq}$/km, which

**Table 1** Overview of data for emissions and costs related to fuel switch

| | System 1 | System 1a | System 1b |
|---|---|---|---|
| | FT-diesel | Diesel | Diesel |
| Heating value ($MJ_{HHV}$/l) | 36.9[a] | 37.9[a] | 37.9[a] |
| Fuel economy NL (km/l) | 14.5 | 14.5 | 14.5 |
| Fuel costs Rotterdam (€/GJ) | 6.5[b] | 9.5[c] | 9.5[c] |
| Distribution costs NL (€/GJ)[d] | 1.33 | 1.33 | 1.33 |
| Total cost of fuel chain (€/km)[e] | $C_b = 0.020$ | $C_r = 0.028$ | $C_r = 0.028$ |
| WTT emissions ($gCO_{2eq}$/km) | 9.4[f] | n.o.r. | 26[g] |
| TTW emissions ($gCO_{2eq}$/km) | 0[h] | 138[gi] | 138[gi] |
| Total emissions ($gCO_{2eq}$/km) | $E_b = 9.4$ | $E_r = 138$ | $E_r = 164$ |
| | System 2 | System 2a | |
| | FT-diesel | Diesel | |
| Heating value ($MJ_{HHV}$/l) | 36.9[a] | 37.9[a] | |
| Fuel economy Mozambique (km/l) | 11.8[j] | 11.8[j] | |
| Fuel costs Rotterdam (€/GJ) | 9.1[b] | n.o.r | |
| Shipping costs (€/GJ) | 0.22[b] | n.o.r | |
| Fuel costs Mozambique (€/GJ) | 8.88 | 9.5[c] | |
| Distribution costs Africa (€/GJ)[k] | 0.70 | 0.70 | |
| Total cost of fuel chain (€/km)[e] | $C_b = 0.030$ | $C_r = 0.033$ | |
| WTT emissions Rotterdam ($kgCO_2/GJ_{HHV}$) | 2.5[b] | n.o.r. | |
| Emissions due to shipping ($kgCO_2/GJ_{HHV}$) | 0.6[b] | n.o.r. | |
| WTT emissions Mozambique ($gCO_2$eq/km) | 6[l] | 26[f] | |
| TTW emissions ($gCO_{2eq}$/km) | 0[h] | 180[m] | |
| Total emissions ($gCO_{2eq}$/km) | $E_b = 6$ | $E_r = 206$ | |

*n.o.r.* Not of relevance

[a]Beer et al. (2001)

[b]Batidzirai et al. (2006)

[c]Average Rotterdam Harbour diesel costs (including oil price) over the year 2005 is 70$/bbl or 0.44 $/l (159 l/bbl). Dollar exchange rate = 1.22 $/€→ 0.36€/l. Energy content diesel = 37.9 $MJ_{HHV}$/l .The price of fossil diesel can than be calculated: 9.5 €/$GJ_{HHV}$. Prices are assumed to be equal worldwide

[d]Hamelinck (2004)

[e]Calculated by adding fuel (sys 1: 6.5 €/GJ; sys 2: 8.88 €/GJ) and distribution costs (sys 1: 1.33 €/GJ; sys 2: 0.70 €/GJ) and convert to €/km (using heating values and fuel economies)

[f]Batidzirai et al. (2006) found GHG-emissions of 3.7 $kgCO_2/GJ_{HHV}$ for FT-diesel produced via EF gasification in Rotterdam (from pyrolysis oil produced from eucalyptus in Mozambique). With assumed FT-diesel heating value of 36.9 MJ/l and a NL fuel economy of 14.5 km/l, we calculated WTT emissions of 9.4 $gCO_2$/km

[g]Edwards et al. (2005) (based on average European 5-seater sedan)

[h]IPCC default

[i]This number is relatively low compared to other studies (182 $gCO_2$/km (Little 1999) or ±152 $gCO_2$/km (Van den Broek et al. 2003)). However, especially the former study is much older and technology has improved since then. Besides, the European Automobile Manufacturers Association has, by means of a voluntary environmental agreement with the European Commission, set a target of 140 $gCO_2$/km for average vehicle emissions from new vehicles sold in Europe by 2008 (Commission of the European Communities 1999). Taking into account that a larger share of the European car fleet is petrol fuelled and petrol-fuelled cars have higher $CO_2$ emissions, we assume that the previously described number of 138 $gCO_2$/km is a realistic number for diesel-fuelled cars in The Netherlands

[j]IEA/WBCSD (2004)

[k]www.shell.com (distribution costs in composition of retail price for diesel in Southern Africa)

[l]Calculated by subtracting the emissions due to shipping from the WTT emissions for the fuel chain to Rotterdam (converted to $CO_{2eq}$/km)

[m]Little (1999)

**Table 2** Overview of data on carbon content related to land use changes

| | Eucalyptus plantation | | Pasture | Cropland |
|---|---|---|---|---|
| Total area (ha) | 50,000 | | 50,000 | 50,000 |
| Rotation (years) | 7 | | n.o.r. | n.o.r. |
| Total years (years) | 21 | | n.o.r. | n.o.r. |
| Carbon fraction (tC/tdm) | 0.5 | | 0.5 | 0.5 |
| Productivity (tdm/ha) | 12[a] | | 3[b] | 0[b] |
| Root/shoot ratio | 0.45[b] | | 2.8[b] | – |
| | After pasture | After cropland | | |
| Soil carbon content (tC/ha) | 45[c] | 35.4[d] | 50 | 30 |

*n.o.r.* Not of relevance

[a]Batidzirai et al. (2006)

[b]Values taken from IPCC Good Practice Guidance for LULUCF (IPCC 2003), the productivity value (0) of cropland follows from the (IPCC) assumption that all crops (including roots) are harvested before land-use switch

[c]Assuming a 10% decrease in soil carbon content with a land use change from pasture to plantation (Guo and Gifford 2002)

[d]Assuming a 18% increase in soil carbon content with a land use change from cropland to plantation (Guo and Gifford 2002)

was found for the upstream processes of conventional diesel in Europe (Edwards et al. 2005).

*Land-use change* We assume, for both systems 1 and 2, that a eucalyptus plantation of 50,000 ha[7] is planted with a rotation length of 7 years. The assumed lifetime of the projects is 21 years. This period is rather long concerning techno-economic projects, but rather low for forestry projects. The influence of the chosen timescale will be analysed later. We consider two different reference land-use types in this study: Pasture, since almost 50 % of the land in Mozambique is in use as permanent pasture (FAO. FAOSTAT Database. http://faostat.fao.org. Cited 3 Nov 2005), and cropland. We postulate that land for bio-energy production is only available after increasing the level of agricultural technology for food production (Smeets et al. 2007; Batidzirai et al. 2006). Leakage effects (Fargione et al. 2008; Searchinger et al. 2008) are thus not studied here, but are considered very important and will, as mentioned before, be discussed later.

To determine the carbon gains and losses related to the change in land-use, changes in carbon content in the different carbon pools need to be estimated. Five major types of carbon pools can be distinguished according to the IPCC Good Practice Guidance for LULUCF (IPCC 2003). In this study, we take into account only aboveground and belowground biomass and soil organic carbon because the other carbon stocks (litter and dead wood) are generally small and can often be ignored. For cropland, it is assumed that the aboveground and belowground biomass

[7]Based on the capacity of the "fictive" CFB conversion facility in Mozambique, The assumed base scale of the CFB conversion facility is 387 $MW_{th}$ on an input basis (Batidzirai et al. 2006). Assuming a plant that operates 8000 h/year, results in an 11.15 PJ demand of energy input. The energy content of the wood is 19.4 GJ/tdm, this means an input of $575 \times 10^3$ tdm/year. The production of eucalyptus is assumed to be 12 tdm/ha $\times$ year, therefore an area of 47,876 ha is needed. In order to account for losses, we assume here an area of 50,000 ha to provide the plant with biomass.

**Table 3** Default reference (under native vegetation) soil organic C stocks

Table 3.2.4 Default reference (under native vegetation) soil organic C stocks ($SOC_{REF}$) (tonnes C per ha for 0–30 cm depth)

| Region | HAC soils | LAC soils | Sandy soils | Spodic soils | Volcanic soils | Wetlands soils |
|---|---|---|---|---|---|---|
| Boreal | 68 | NA | 10[#] | 117 | 20 | 146 |
| Cold temperate, dry | 50 | 33 | 34 | NA | 20 | 87 |
| Cold temperate, moist | 95 | 85 | 71 | 115 | 130 | 87 |
| Warm temperate, dry | 38 | 24 | 19 | NA | 70 | 88 |
| Warm temperate, moist | 88 | 63 | 34 | NA | 80 | 88 |
| Tropical, dry | 38 | 35 | 31 | NA | 50 | 86 |
| Tropical, moist | 65 | 47 | 39 | NA | 70 | 86 |
| Tropical, wet | 44 | 60 | 66 | NA | 130 | 86 |

Source: IPCC (2003)

is 0 tdm/ha, since all crops are assumed to be harvested before the land is switched to a biomass plantation (IPCC 2003). The other belowground biomass values are estimated using root-to-shoot ratios as provided by the IPCC (2003). Data on soil carbon content are based on a study by Guo and Gifford (2002). They concluded that a shift from pasture to plantation will generally result in a decrease of soil carbon content with 10%, a shift from cropland to plantation will lead to a mean increase of 18%. Initial soil carbon content of grasslands and croplands were estimated to be 50 tdm/ha and 30 tdm/ha respectively (confirmed by Cowie, pers.comm) based on indicative values for native vegetation and cropland as presented in the IPCC Good Practice Guidance for LULUCF; considering a tropical dry to moist climate for Mozambique (Table 3) and relative stock change factors for the cropland management activities as presented in Table 4.

*Transaction costs and risks* Michaelowa et al. (2003) analysed the relation between project size and transaction costs for CDM projects. They found transaction costs of 0.1–1.0 €/ton $CO_2$ for large (20,000 ton $CO_2$/year–200,000 ton $CO_2$/year) to very large (>200,000 ton $CO_2$/year) projects. To reduce risks of CDM projects, often a so-called non-delivery buffer is used. The percentage of this buffer can vary, and is mostly in between 10–30% (UNDP 2003; IFC 2006). Here we use a value of 20%.

### *3.1.3 Results*

Figures 4 and 5 show the cumulative carbon storage over the lifetime of the plantation compared to the different baselines. From Fig. 4 it can be seen that the establishment of a eucalyptus plantation on pasture land firstly leads to a decrease

**Table 4** Relative stock change factors for cropland

| | Land use factor | Tillage factor | Input factor | |
|---|---|---|---|---|
| Estimated SOC native (tC/ha) | Long term cultivated, tropical, dry | Full tillage, tropical | Low, tropical, dry | Estimated SOC cropland (tC/ha) |
| 50 | 0.69 | 1.0 | 0.92 | 31.7[a] |

[a]Calculated by multiplying the reference native SOC value with all three stock change factors ($50 \times 0.69 \times 1.0 \times 0.92 = 31.7$). The value should, however, be seen as a rough assumption

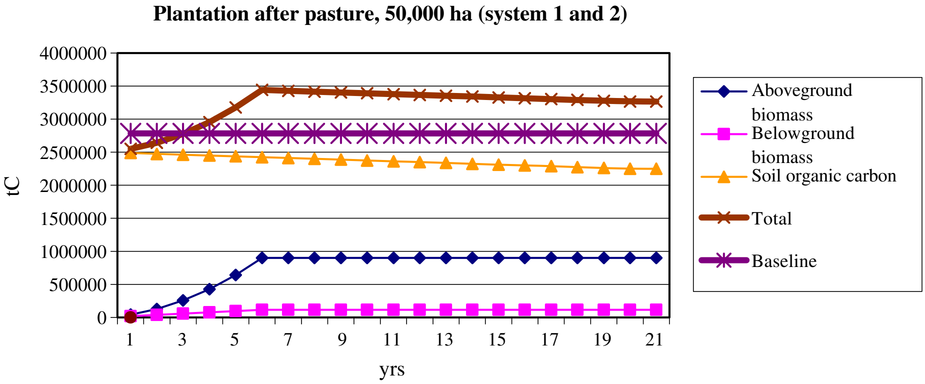


**Fig. 4** Cumulative carbon storage in the Eucalyptus plantation compared to the carbon storage in the baseline (pasture)

in carbon. Later, the carbon accumulation in the plantation is above the baseline. Establishing a plantation on former cropland has a positive effect on carbon stocks from the beginning. The exact amount of carbon sequestration that can be attributed to both scenarios depends on the accounting rule to be applied and the chosen timeframe. The total amount of $CO_2$ sequestration for the two scenarios, calculated with the 4 different accounting methods (Stock Change (SC), Average Storage (AS), Ton Year (TY) and Temporary Crediting (TC)) is given in Table 5.[8] For all methods, a discount rate of 10% is used. Since the fuel efficiency in trading systems 1 and 2 is different, differences exist between calculated values for both systems. Table 5 shows that the establishment of a plantation on former pasture land, generates far lower carbon credits than on former cropland, independent of the accounting rule applied.

Since the carbon benefits occur mainly in the first 20 years, the carbon benefits per km would be considerably lower if they would be attributed to a longer project period; indicating the impact of project lifetime on the results.

The total emission reductions, expressed in kilometers driven in order to be able to compare the outputs of systems with different efficiencies, are shown in Fig. 6. The first four scenarios represent the pasture (P) baseline situation, whereas cropland (C) is the baseline vegetation in the last four scenarios. For both baselines, four different accounting rules (Stock Change (SC), Average Storage (AS), Ton Year (TY) and Temporary Crediting (TC)) are applied. The total emission reductions do not vary much between the physical and emission credit systems, if considering the complete chains (1b and 2). Larger differences are however found between reference systems 1a and 1b and between the cropland an pasture scenarios. The effect of the different carbon accounting methods is largest in the cropland reference scenarios, as already could be seen in Tables 5 and 6.

[8]The results are converted to $CO_2$/km to be compatible with formula (2); the total amount of harvest over 21 years (tdm) is converted to GJ, assuming eucalyptus has a higher heating value of 19.4 GJ/tdm. The conversion efficiency from biomass via pyrolysis oil to FT-fuel is 48%. (conversion efficiency from biomass to pyrolysis oil is 67% and to FT is 71% (Batidzirai et al. 2006)). To convert to km driven, the heating value of FT-diesel (36.9 MJ/l) and the fuel economy of 14.5 km/l are used.

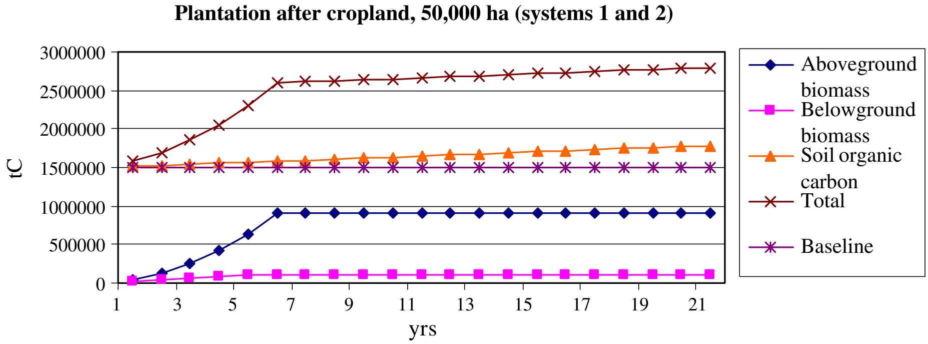


**Fig. 5** Cumulative carbon storage in the Eucalyptus plantation compared to the carbon storage in the baseline (cropland)

**Table 5** $CO_2$ benefits ($gCO_2$/km) for 2 baseline scenarios; based on 4 accounting rules and a lifetime of 21 years

| Accounting method | $E_L$ Plantation after pasture (1) | | $E_L$ Plantation after cropland (2) | |
|---|---|---|---|---|
| | System 1 | System 2 | System 1 | System 2 |
| Stock change | 40 $gCO_2$/km | 49 $gCO_2$/km | 99 $gCO_2$/km | 122 $gCO_2$/km |
| Average storage | 35 $gCO_2$/km | 42 $gCO_2$/km | 86 $gCO_2$/km | 105 $gCO_2$/km |
| Ton-year | 22 $gCO_2$/km | 27 $gCO_2$/km | 30 $gCO_2$/km | 36 $gCO_2$/km |
| Temporary credits | 40 $gCO_2$/km | 49 $gCO_2$/km | 99 $gCO_2$/km | 122 $gCO_2$/km |

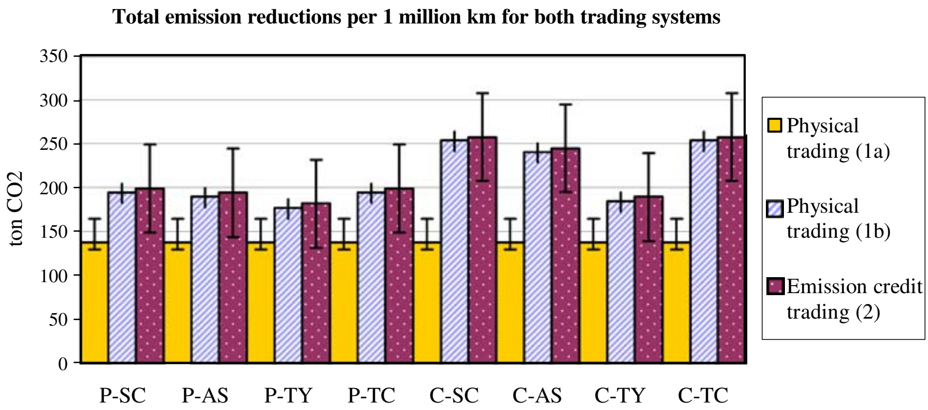


**Fig. 6** Total emission reduction per 1 Mkm driven for the two trading systems (3 reference situations) with two different baseline vegetations and four accounting rules (timescale 21 years)

**Table 6** $CO_2$ benefits ($gCO_2$/km) for 2 baseline scenarios; based on 4 accounting rules and a lifetime of 60 years

| Accounting method | $E_L$ Plantation after pasture (1) | | $E_L$ Plantation after cropland (2) | |
|---|---|---|---|---|
| | System 1 | System 2 | System 1 | System 2 |
| Stock change | 11 $gCO_2$/km | 14 $gCO_2$/km | 27 $gCO_2$/km | 34 $gCO_2$/km |
| Average storage | 10 $gCO_2$/km | 12 $gCO_2$/km | 24 $gCO_2$/km | 29 $gCO_2$/km |
| Ton-year | 6 $gCO_2$/km | 8 $gCO_2$/km | 8 $gCO_2$/km | 10 $gCO_2$/km |
| Temporary credits | 11 $gCO_2$/km | 14 $gCO_2$/km | 27 $gCO_2$/km | 34 $gCO_2$/km |

The breakdowns of carbon gains in Fig. 7 show that emissions in the reference energy system have the largest impact on the total emission reductions. Land use changes have a considerable contribution, especially in the cropland baseline scenarios. Due to the higher emission in the reference system in Mozambique (206 $gCO_2$/km), compared to the Netherlands (164 $gCO_2$/km), the effect of fuel switch is largest in the emission credit system. The total emission reductions are, however, almost equal for both systems (Fig. 6) due to the considerable amount of carbon credits reserved for insurance in system 2.

The costs of $CO_2$-avoidance are shown in Fig. 8. The results show that for all scenarios the physical trading systems deliver carbon credits with the highest benefits, although the uncertainties are high. Due to the largely fluctuating oil prices, economic benefits can turn into costs as soon as diesel prices start to drop.

In Figs. 9, 10 and 11 the effect of parameter variation, within uncertainty ranges, on the cost of CO2 avoidance for the different trading systems is shown for one scenario: pasture as baseline vegetation and temporary crediting as accounting method. The results show that the respective prices of fossil diesel and FT-diesel have by far the largest influence on the results. Fuel prices thus dominate the economic results.

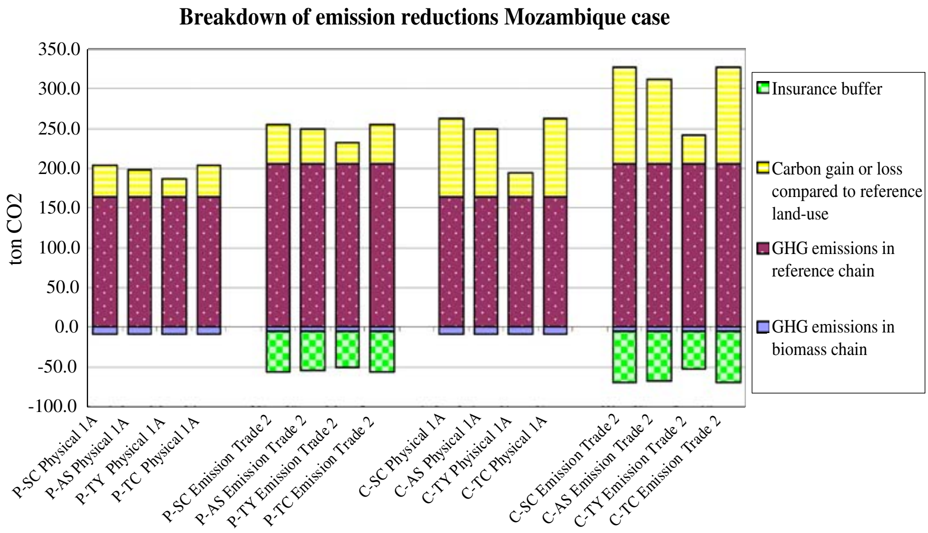


**Fig. 7** Avoided $CO_{2eq}$-emissions per 1,000,000 km driven for 2 trading systems, 2 baseline vegetations and 4 different accounting methods

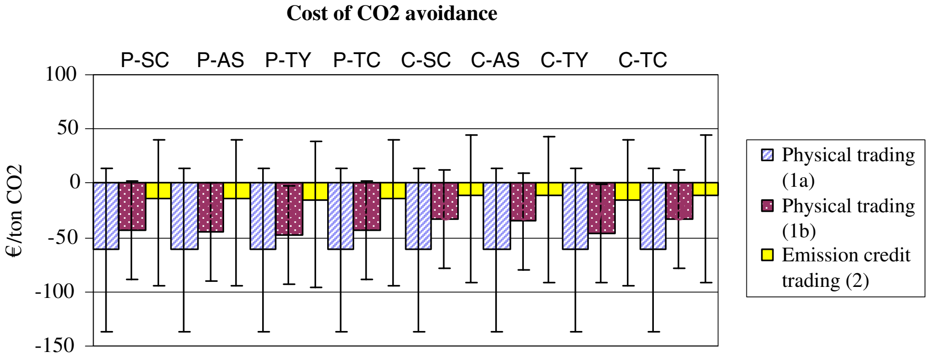


**Fig. 8** Cost of CO2 avoidance (€/ton $CO_2$) for the two trading systems (3 reference situation) with two different baseline vegetations and four accounting rules (lifetime 21 years)

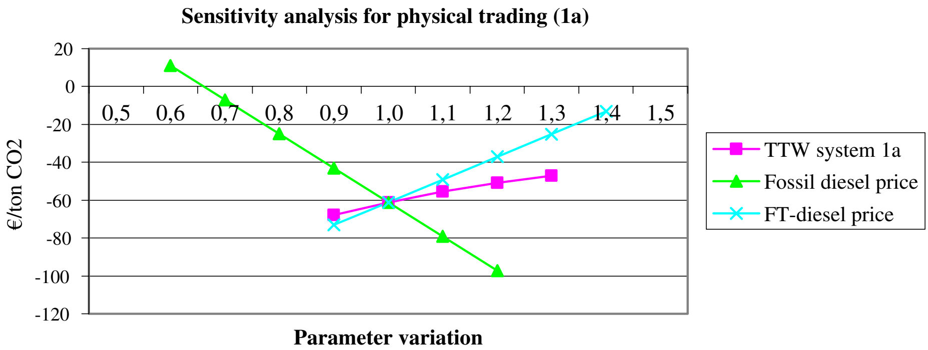


**Fig. 9** Effect of parameter variation on cost of CO2 avoidance (1a)

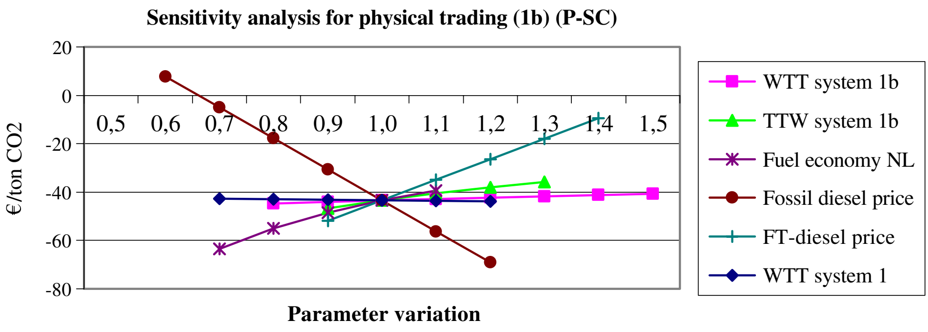


**Fig. 10** Effect of parameter variation on cost of CO2 avoidance (1b) (P-TC)

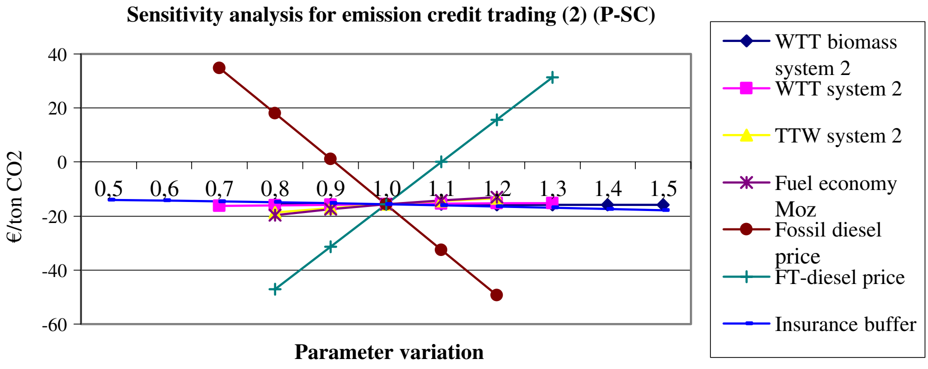


**Fig. 11** Effect of parameter variation on cost of CO2 avoidance (2) (P-TC)

From the emission reduction related parameters, the tailpipe emissions (TTW) in the reference energy systems and the fuel economy have the largest influence on the results.

Although the benefits per ton of carbon avoided can be a good indicator for the performance of the respective trading systems, other indicators can also be helpful in analyzing the trade-off between both systems. Therefore, we also analyze the financial returns per hectare at different carbon prices (Fig. 12).

Results are shown for the two baseline vegetation scenarios, and Temporary crediting accounting method. The results show that with current carbon prices of 20–30 €/ton $CO_2$, physical trading is more beneficial. When carbon prices increase to over 85 €/ton $CO_2$, emission credit trading becomes more attractive than physical trading (1a) in one scenario (plantation based on former cropland).

### *3.1.4 Discussion and conclusion*

The results have shown that the carbon benefit of physical trading depends largely on the reference system used (1a or 1b). Although the effect of ignoring or including upstream emissions was relatively small here, the benefits related to the switch in

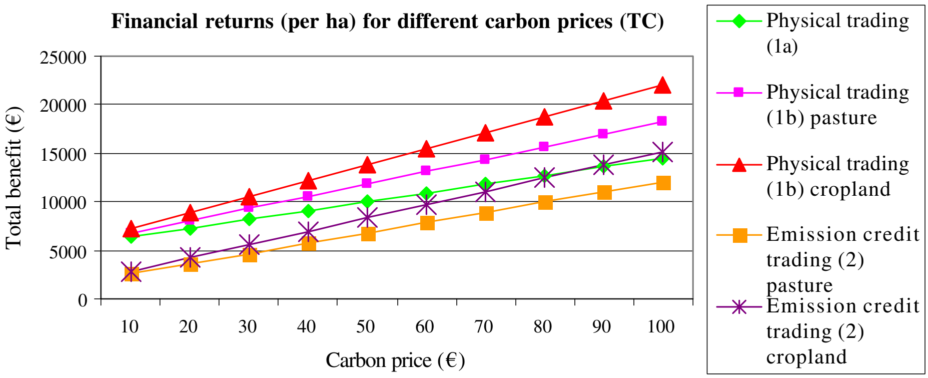


**Fig. 12** Financial returns per hectare at different carbon prices

land-use (excluding leakage) were large and almost equal to the benefits related to the fuel switch. Due to limited available information on SOC values, however, these results should be considered with care. A comparison of the two trading options (system 1 and system 2) showed that there is only a very small difference in carbon gains, if considering the whole chain (ref 1b and 2). Emission credit trading delivers slightly more credits than physical trading.

The economic performance of the emission credit trading system is, however, much lower than the performance of the physical trading system. This difference can not be attributed to the extra transaction costs involved in system 2; these have a negligible effect. The main difference in economic benefits is related to the relatively more expensive production costs of FT-diesel in Mozambique. Even though in the latter system no costs for overseas transport are made, the production costs in Mozambique are still larger than the production costs in Rotterdam. Only when carbon prices triple compared to the price today, emission credits trading can become financially more attractive, in this case study.

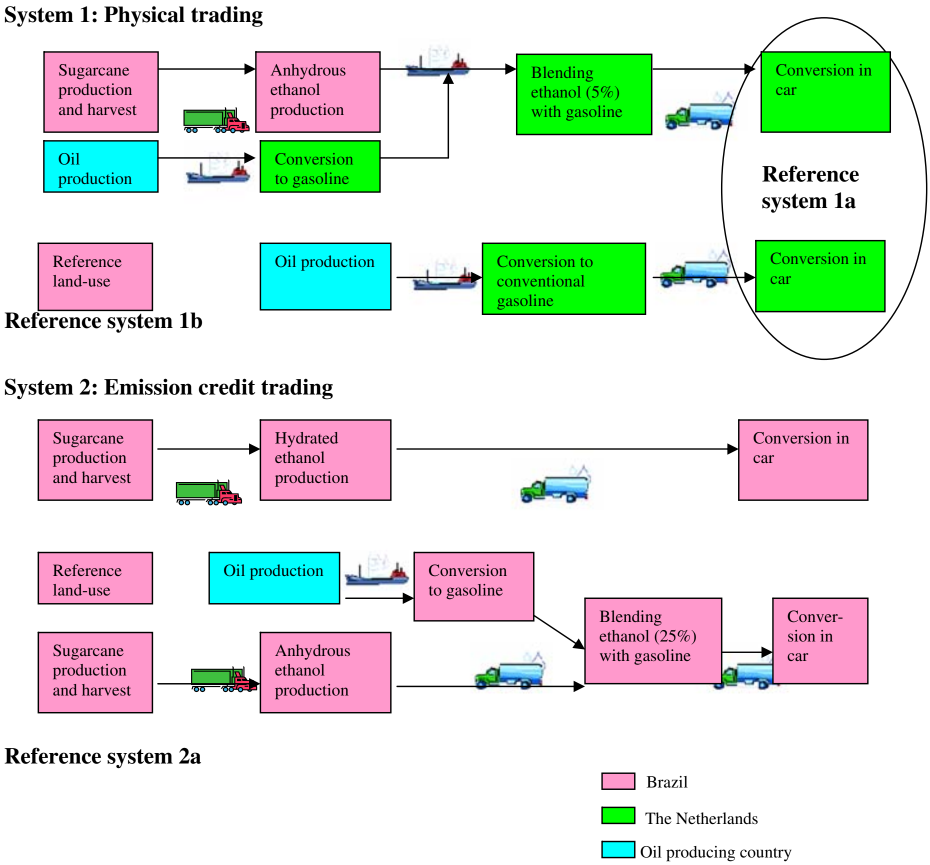


**Fig. 13** Brazil: biomass trading systems with reference systems

It turned out that the total amount of credits, derived for the land use change part of the projects, vary greatly per accounting method, previous land use and timeframe. Between the different accounting methods, a large difference also exists in the moment when the credits are generated. The Stock Change method generates credits as soon as the carbon stocks in the project are larger than in the baseline, but credits should also be "paid", as soon as carbon stocks are lower in the project than in the baseline, as is the case in the first period of the plantation after pasture. Because of the discount rate, credits earned at a later phase have a smaller value, and the depths that are paid at the beginning have a relatively larger impact. This effect is not apparent in the Average Storage approach, since the average carbon storage is calculated and no credits have to be "paid" at the start.

In conclusion, the case study results showed that in this case, there are no significant differences in the amount of carbon credits per km for the two trading options if the total chains are compared. However, since carbon benefits related to land use change can at this moment not be accounted for in the physical trading systems, the emission trading system will generate more carbon credits than the physical trading system although it goes with higher costs. The emissions in the reference energy systems had the largest influence on the amount of carbon credits available in both systems, whereas the differences in fuel prices dominate the financial results. Due to the large scale of the fictive CDM project, transaction costs had a negligible influence on the total costs. Both different baseline vegetations and different accounting rules had a considerable influence on the results. With current carbon prices, physical trading system is most beneficial in economic sense.

## 3.2 Brazil

The second case study country is Brazil. Brazil has a unique position in the bio-fuel market since it is the world's largest ethanol fuel producer as well as consumer. It gained valuable experience in the various aspects of sugarcane ethanol production during the 30 years of the Brazilian Alcohol Program (PROALCOOL). Currently, the ethanol blending requirement in Brazil is 25%.

### *3.2.1 Case description*

Physical trading is represented in system 1 (Fig. 13) Here, ethanol, produced from sugarcane in Brazil, is transported overseas to the Rotterdam harbour where it is mixed with conventional gasoline to form a blend fuel (5%, since this is the current maximum according to the fuel quality directive of the EU (98/70/EC)[9]). The fuel is transported to fuel stations where cars are filled and final conversion occurs in the vehicle. Reference system 1a corresponds to the tailpipe emissions of conventional gasoline cars in the Netherlands, whereas in reference system 1b also upstream emissions of gasoline production and reference land use are taken into account.

Since alcohol production for the blend of up to 25% is not a candidate for CDM projects in Brazil (it corresponds to a baseline before the base year for the Kyoto Protocol) (Coelho et al. 2005), we consider as the emission credit trading scenario

[9] Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel fuels and amending Council Directive 93/12/EEC.

a project where ethanol vehicles (100% hydrated) are subsidized. The scenario is based upon an agreement between the German and Brazilian governments, where Germany plans to invest a total amount of 40 million dollars, subsidizing 100,000 alcohol vehicles, to purchase carbon credits as part of its Kyoto Protocol commitments. System 2, therefore, represents the production of hydrated ethanol (100%) from sugarcane in Brazil and the conversion in the alcohol vehicle. Reference system 2a indicates the baseline situation in Brazil: the production of anhydrous ethanol and gasoline that are mixed in a blend of 25% and converted in the car.

*Land use* Recent studies have indicated that it is possible to avoid leakage due to bio-energy production if, at the same time, the productivity of agriculture and cattle-breeding is improved (Smeets and Faaij 2008). According to Coelho et al. (2005) and Macedo et al. (2004) competition between bio-fuel crops and food crops has, until now, been avoided in Brazil; the great rise in productivity resulting from technological developments allowed the growth of sugarcane production without excessive land-use expansion and the expansion of agriculture over the past 40 years took place mostly in degraded pasture areas. In this case study, we also assume no leakage effects for land-use. However, as mentioned before, the current debate on carbon penalties related to displacements is a serious issue of concern and will be discussed later.

### *3.2.2 Data*

*Fuel switch* In the physical trading system (system 1), fuel costs are the costs of ethanol delivered in the Rotterdam Harbour (production plus transportation costs) added to these costs are the costs of mixing the blend and distributing it to the fuel stations. Total costs are expressed in €/$km_{(EToH)}$ (Table 7). In the reference case, fuel costs are composed of the gasoline costs in the Rotterdam harbour, plus the distribution costs for delivery at the fuel stations. $CO_2$-eq emissions in system 1 consist of the emissions related to the production, conversion, transportation of ethanol (WTT). Emissions during conversion in the car (TTW) are assumed to be zero for bio-fuels (IPCC default approach). Emissions in reference system 1a relate to the tailpipe (TTW) emissions of conventional gasoline cars in the Netherlands. In reference system 1b, well-to-wheel emissions for gasoline in average Dutch gasoline cars are considered.

In the CDM scenario (system 2) we assume that the cost of the project is 40 million dollars. 100,000 Ethanol vehicles will be subsidised with this money. We assume that the ethanol vehicles will be intensively used, driving at least 25,000 km/year. With this consumption pattern, the cars are assumed to have a lifetime of 10 years. It should be noted that a methodology for this CDM project has to date neither been approved by, nor submitted to, the CDM Executive Board.

*Land-use change* Data on above- and belowground carbon contents have been estimated using data from the IPCC Good Practice Guidance for LULUCF (IPCC 2003). Data on soil carbon content are taken from Silveira et al. (2000). They found a decrease in SOC of 24% (over 20 years) when forest is turned into pasture land in Brazil, followed by a decrease of 22% over 20 years when a sugarcane plantation is established on the pasture land. Initial (forest) SOC was found to be 61.5 tC/ha

**Table 7** Overview of data for emissions and costs related to fuel switch (Brazil)

| | System 1 | System 1a | System 1b |
|---|---|---|---|
| | Gasohol(E5) | Gasoline | Gasoline |
| Energy content ($GJ_{HHV}/tonne_{dry}$) | 29.8[a] | 47.3[a] | 47.3[a] |
| Density ($kg/m^3$) | 791[a] | 745[a] | 745[a] |
| Energy content ($MJ_{HHV}/l$) | 23.6 | 35.2 | 35.2 |
| Fuel efficiency ($km/GJ_{fuel}$) | 440[b] | 430[b] | 430[b] |
| Fuel costs ethanol ($/l) | 0.23[c] | | |
| Fuel costs gasoline ($/bbl) | | 65[d] | 65[d] |
| Mixing costs (€/l) | 0.05[e] | | |
| Distribution costs NL (€/l) | 0.1[f] | 0.1[f] | 0.1[f] |
| Total costs of fuel chain (€/GJ) | 14.36 | 12.35 | 12.35 |
| Total cost of fuel chain (€/km) | $C_b = 32.6 \times 10^{-3}$ | $C_r = 28.7 \times 10^{-3}$ | $C_r = 28.7 \times 10^{-3}$ |
| WTT emissions ($gCO_{2eq}/km$) | 28[g] | n.o.r. | 28[g] |
| TTW emissions ($gCO_{2eq}/km$) | 0[h] | 168[g] | 168[g] |
| Total emissions ($gCO_{2eq}/km$) | $E_b = 28$ | $E_r = 28$ | $E_r = 28$ |
| | System 2 | System 2a | |
| | Ethanol (E100) | Gasohol (E25) | |
| Energy content ($GJ_{HHV}/tonne_{dry}$) | 29.8[a] | 42.7[a] | |
| Density ($kg/m^3$) | 791[a] | 756.5[a] | |
| Energy content ($MJ_{HHV}/l$) | 23.6 | 32.3 | |
| Fuel efficiency ($km/GJ_{fuel}$) | 540[b] | 440[b] | |
| Average (km/year) | 25,000 | | |
| Lifetime car (years) | 10 | | |
| Total project costs (M€) | 40 | | |
| WTW gasoline brazil ($kgCO_2/l$) | | 2.82[i] | |
| WTW anhydr ethanol Brazil ($kgCO_2/l$) | | 0.4[j] | |
| WTW hydr. ethanol Brazil ($kgCO_2/l$) | 0.39[k] | | |
| WTW total ($kgCO_2/l$) | 0.39 | 2.212 | |
| WTW total (gCO2/MJ) | 16.5 | 68.6 | |
| Total emissions ($gCO_{2eq}/km$) | $E_b = 31$ | $E_r = 156$ | |

[a]Hamelinck (2004) Appendix, Table A.1. For system 2a (Gasohol E25) energy content and density values have been calculated based on a mixture of 25%$_{vol}$ ethanol and 75%$_{vol}$ gasoline

[b]Hamelinck (2004). Table 8, Page 39. (For gasohol E5 and E25 the values from E10 are taken)

[c]Based on data from Coelho et al. (2005), average export price in the period 2001–2003

[d]Rotterdam Harbour price of gasoline at the beginning of year 2006 (www.iea.org)

[e]Elam (2000)

[f]Van den Broek et al. (2003)

[g]EUCAR et al. (2005)

[h]Biofuels assumed to have zero CO2 emissions (TTW)

[i]Macedo et al. (2004)

[j]Macedo et al. (2004). Ethanol life-cycle emissions 34.5 $kgCO_2$/ton of sugarcane. 86,0 l anhydrous ethanol per ton of sugarcane

[k]Macedo et al. (2004). Ethanol life-cycle emissions 34.5 $kgCO_2$/ton of sugarcane. 88.6 l hydrous ethanol per ton of sugarcane

(Silveira et al. 2000). We assume in this study that sugarcane SOC is equal to cropland SOC, this will be discussed later. An overview of the data on carbon content related to land use changes for system 1 and 2 is provided in Table 8.

**Table 8** Overview of data on carbon content related to land use changes for systems 1 and 2

| | Sugarcane plantation | | Pasture | Cropland |
|---|---|---|---|---|
| Total area (ha) | 45,000[a] | | 45,000[a] | 45,000[a] |
| Productivity (tdm/ha) | 65 | | – | – |
| Carbon fraction (tC/tdm) | 0.5 | | 0.5 | 0.5 |
| Aboveground biomass (tdm/ha) | 0[b] | | 6.2[b] | 0[b] |
| Root/shoot ratio (tdm/tdm) | 0[b] | | 1.6[b] | 0[b] |
| | After pasture | After cropland | | |
| Soil carbon content (tC/ha) | 36.5[c] | 36.5[c] | 47.0[c] | 36.5[c] |

[a] Amount of extra hectares needed to have 100,000 ethanol vehicles driving 25,000 km per year with a fuel economy of 8 l/km. 88.6 l of hydrous ethanol can be produced from 1 ton of sugarcane and 65 tons of cane are produced from 1 ha. The baseline is 10,000 ha which is needed to have E25 vehicles driving $2.5 \times 10^9$ km/year

[b] IPCC Good Practice Guidance for LULUCF (IPCC 2003)

[c] Silveira et al. (2000) found an initial SOC of 61.5 tC/ha in Sao Paulo forest. Conversion to pasture land lead to a SOC decrease of 24%, resulting in a SOC of 47 tC/ha for pasture land. Final conversion into sugarcane lead to a further decrease in SOC of 22%, meaning a SOC of 36.5 tC/ha on sugarcane plantations

*Transaction costs and risks* Transaction costs are assumed to be already included in the costs of the CDM project (system 2). Risks are assumed to be insured by using an insurance buffer of 20%.

### *3.2.3 Results*

Since it is assumed that cropland substitution (sugarcane production on former cropland) has no significant influence on carbon storage, only carbon changes related to the replacement of pasture land by sugarcane plantations are reflected. From Fig. 14, it can be seen that the total carbon storage decreases when sugarcane crops are grown on previous pasture lands (approximately 0.5 Mton C on 45,000 ha over 20 years). This carbon loss can almost completely be attributed to decreases in soil carbon content resulting from the land use change.

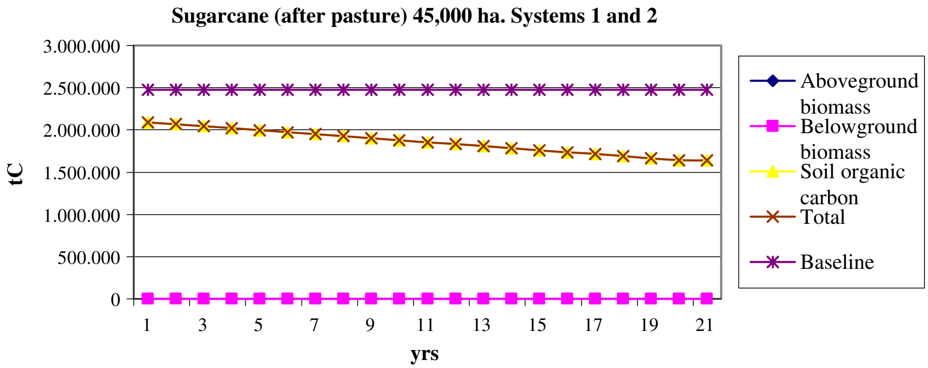


**Fig. 14** Cumulative carbon storage in the sugarcane plantation compared to the carbon storage in the baseline (pasture)

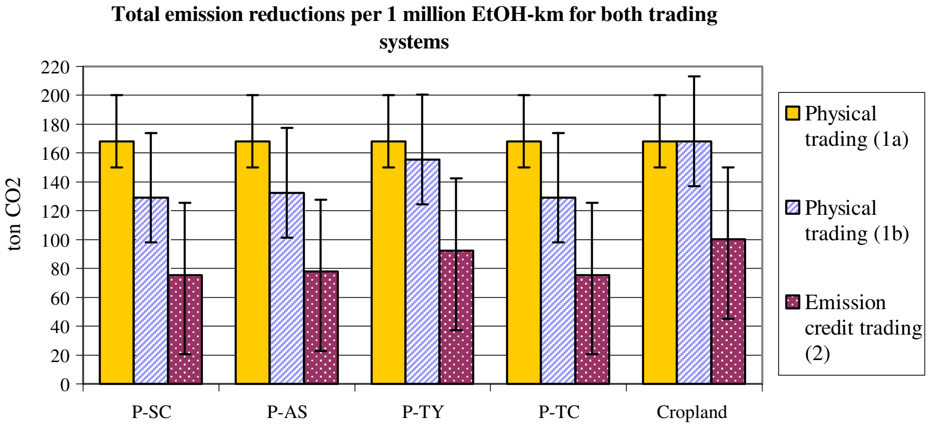


**Fig. 15** Total emission reductions per 1,000,000 EtOH km driven for system 1 and 2, for two vegetation baselines and four accounting rules

Figure 15 shows that including the carbon effects of upstream emissions and land-use changes (1b) results in less carbon credits compared to the same scenario where these steps are excluded (1a). This is mainly due to land-use changes since this difference does not appear in the cropland scenario. Emission credit trading delivers the fewest emission credits in all scenarios. The reason for this can be found when looking at the breakdowns in Fig. 16. Applying different accounting rules has a considerable influence on the results, as we have already seen in the Mozambique case study.

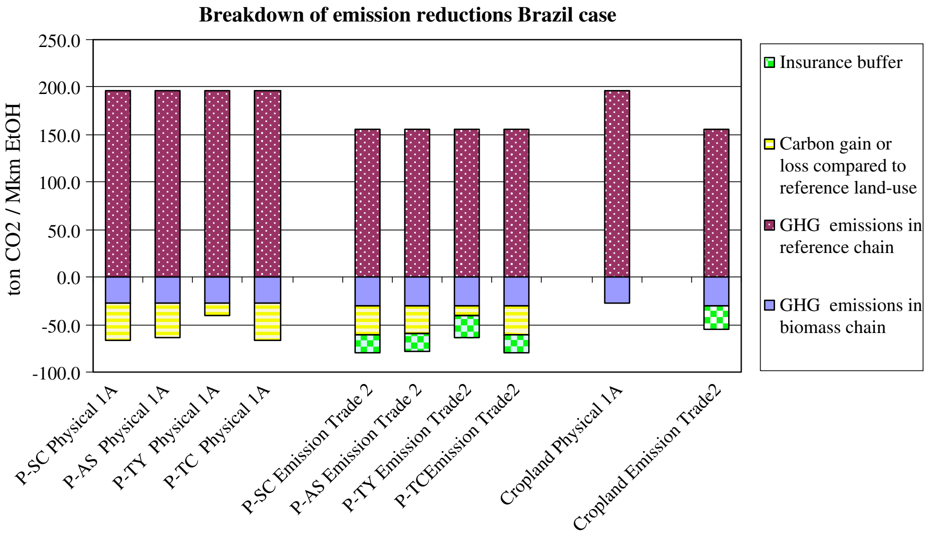


**Fig. 16** Avoided $CO_{2eq}$-emissions per 1,000,000 EtOH km driven for 2 trading systems, 2 baseline vegetations and 4 different accounting methods

Figure 16 shows that (avoided) emissions in the reference system account for the largest part of the emission reductions. Emission in the biomass chain (WTT) and emissions related to land-use change (mainly SOC) account for a decrease in the avoided emissions. The emissions in the reference energy system in emission trading (E25 Brazil) are considerably lower than the emissions in the physical trading reference system. The reason is that in the baseline (E25) already 25% of gasoline is replaced by ethanol. GHG emissions in the biomass chain and carbon losses due to land-use change are similar to the physical trading scenario. However, additional losses result from the extra emission credits reserved in an insurance buffer.

In Fig. 17, the costs of CO2 avoidance are displayed. The results show that in contradiction to the Mozambique case study, here, for all scenarios costs are associated with $CO_2$ avoidance. Costs of $CO_2$ avoidance in physical trading are mainly given by relative differences in oil and ethanol prices (taxes and import tariffs were not taken into account). With current gasoline and ethanol prices, the physical trading systems produce carbon credits with a price of 20–30 euros, but due to fluctuating oil prices, uncertainties are high. With increasing oil prices, the costs of physical trading will be reduced. The costs of carbon credits in the emission credit trading scenario are largely given by the investment of 40,000,000 dollars that is foreseen to facilitate the purchase of a new fleet of 100,000 ethanol vehicles. In the physical trading scenarios, no such investments are necessary for the cars, since the fuel can be used in the currently available vehicles. Uncertainties in the emission credit trading system (2) are related to the uncertainties in the amount of $CO_2$ avoided. That is, amongst others, determined by the amount of kilometres that the fleet will drive, the lifetime of the cars and the fuel efficiency of the fleet.

Sensitivity analyses have shown that fuel prices (both ethanol and gasoline) have the largest influence on the costs of $CO_2$ reduction in the physical trading scenarios. The WTW emissions in the gasoline fraction of the reference energy system, the assumed amount of kilometres driven per year, the lifetime of the cars and the assumed project lifetime have a considerable influence on the results in the emission credit trading system.

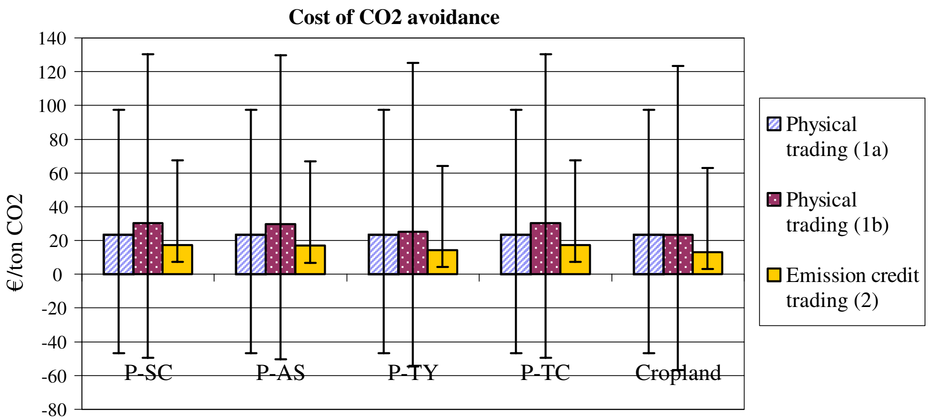


**Fig. 17** Costs of CO2 avoidance (€/ton $CO_2$) for physical trading (1a and 1b) and the emission credit trading system with two different baseline vegetations and four accounting rules

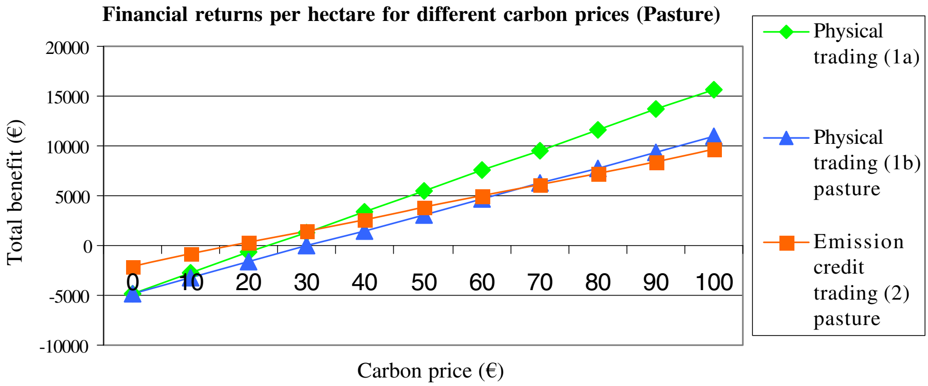


**Fig. 18** Financial returns at different carbon prices

Figure 18 shows the financial returns per hectare, at different carbon prices, for both trading systems with pasture as baseline vegetation scenario. Emission credit trading is favourable at low carbon prices; with increasing carbon prices physical trading becomes more financially attractive. The switching point, with current oil and ethanol prices, is around 30 € per ton of carbon for system 1a, and around 70 € per ton of carbon for system 1b (including upstream emissions and land-use changes).

### *3.2.4 Discussion and conclusion*

Due to the strict rules for registration of CDM or JI projects, all carbon fluxes related to the project must be taken into account in emission credit trading. In physical trading, however, current practice is to only consider the avoided emissions related to the conversion of the substituted fossil fuel. Especially when this change in land-use leads to carbon losses, this current approach can be very precarious.

From Fig. 15, it could be seen that the carbon losses related to land-use change occur primarily during the first 20 years after the sugarcane plantation is established. In this study, we attributed these carbon losses completely to the first 20 years of ethanol production. Consequently, if ethanol production from the established sugarcane plantation is continued after 20 years, the carbon losses per km driven would be lower. This indicates again the large influence of the chosen time scale on carbon balances. Fuel prices are, also in this case study, one of the most important variables determining the cost of $CO_2$ avoidance. Given the large uncertainties and fluctuations concerning fuel prices in the future, it might be hard to predict the financial gains or losses related to the switch of fossil fuels to bio-fuels. However, if we expect fossil fuel prices to increase over the years, an increase in bio-fuel trading can be expected. It is then important to ensure that this increase will not lead to carbon losses related to land-use changes.

## 4 Discussion

– In the physical trading scenarios, we did not take into account an insurance buffer since few is known about such practices in physical trading, in contradiction to

CDM projects. However, some insurance might be desired to ensure a reliable supply of resources. This would increase the costs of this trading system.

- In the Mozambique case study we assumed a larger conversion facility in the Rotterdam Harbour (1000 $MW_{th}$) than in Mozambique (387 $MW_{th}$). Although Rotterdam Harbour is one of the largest harbours in the world, where, in theory, large amounts of biomass could be imported and converted, these fictive examples had considerable impacts on the results.
- We assumed sugarcane as cropland and the IPCC Guidelines (2003) prescribe no significant changes in carbon content if cropland remains cropland. Sugarcane is, however cultivated in a ratoon system and only every four or five years, the complete plants are removed and replaced by new plants. Sugarcane is therefore closer to wood species then 'normal' crops. The assumption of no carbon change when cropland is replaced by sugarcane is therefore on the conservative side, there is probably an increase in SOC, but the exact numbers are not known.
- Throughout this study, it appeared very difficult to find reliable sources for SOC values. The values we used in this report are based on IPCC default assumptions (IPCC 2003), on a meta-analysis by Guo and Gifford (2002) that was based on several studies and for Brazil specific data for Sao Paulo could be found. Furthermore, our assumptions were confirmed by Cowie (pers. comm.). However, one should be careful with conclusions based on non-measured soil carbon content data. Especially since the SOC values had a considerable impact on the results.
- Four accounting rules were explored in the case studies of this report. Although currently a decision for the Temporary Crediting method has been made, we still consider it valuable to analyse the effect that the choice for a certain method can have on the results. Besides, the described accounting rules may be reconsidered in a new accounting period.

The case study results showed that direct land use changes can have such a large influence (both positive and negative) on total carbon balances of the trading systems, mainly due to changes in soil carbon, that it would be dubious to ignore them (as currently done in physical trading). With the implementation of a certification system[10] it could be ensured that no carbon losses occur during production of the biomass. Although carbon changes from land use changes can be taken into account in CDM and JI projects, the chosen timeframe is rather arbitrary and has a large influence on the results as shown in this study.

In this study, carbon leakage effects from indirect land-use change (ILUC), which could have large consequences on the GHG balance of a biofuel (Fargione et al. 2008; Searchinger et al. 2008), are excluded. We acknowledge the importance and relevance of studying these effects and to including them into carbon accounting of both trading systems. Considering the results of this study, however, we refer to recent studies that have indicated that it is well possible to avoid leakage due to bio-energy production if, at the same time, the productivity of agriculture and cattle-breeding is improved (e.g. Smeets and Faaij 2008). Furthermore, the exclusion of

[10]This certification system would be needed for biomass from non-Annex I countries only, since carbon stocks in Annex I countries are accounted for in National GHG Inventories anyhow.

leakage effects has been done for both trading systems and for both case studies which makes the results at least comparable.

This study has further shown that transportation and transaction costs have a negligible influence on the financial results in large scale trading systems as explored in this study. Since oil prices, although fluctuating, are almost the same anywhere in the world (thus similar for importing and exporting country), the cheapest trading system to reduce GHG-emission depends mainly on 1) the amount of GHG-emission that can be avoided in the exporting respectively importing country, where the balance between the emissions in the baseline and the emissions in the bio-fuel system turns out to be most important and 2) the associated cost of the bio-fuel system in either of those countries. If the conversion of biomass is cheaper in the importing country, physical trading would be beneficial. If, on the other hand, conversion is cheaper in the country of biomass origin, both emission credit trading and physical trading are good alternatives since transportation costs are found to be negligible at large trading scales. It then depends on other choices, which trading option is favourable. Besides, subsidies, taxes, policies and legislation might affect both bio-fuel trading and domestic production opportunities.

## 5 Conclusions and recommendations

The results of both case studies are summarized in Table 9. The total emission reductions ($tCO_2$/km; $tCO_2$/ha) in the Brazilian case study are mostly higher than in Mozambique. The costs of $CO_2$ avoidance (€/$tCO_2$) are, however, much higher in the Brazilian case study as compared to Mozambique, where there are benefits instead of costs. This effect also becomes apparent in the financial returns. The optimization method to be used depends on individual preferences (see also Schlamadinger et al. 2005). Moreover, for companies, taxes and import tariffs, that were not included in this case study, play a great role, whereas governments can influence these factors to optimize their strategies. Besides, other issues than $CO_2$ avoidance and costs may play a role in defining the best trading option.

Given the large global bio-energy production potential, how should we make optimal use of this renewable source, regarding, amongst others, land-use, costs and avoided emissions? To answer this question, various factors that have been discussed

**Table 9** Overview of main results from both case studies

| Optimization methods↓ | Baseline | Pasture | | | Cropland | | |
|---|---|---|---|---|---|---|---|
| | Trading system | 1a | 1b | 2 | 1a | 1b | 2 |
| Total emission reductions ($tCO_2$/Mkm) | Moz | 138 | 194 | 199 | 138 | 254 | 257 |
| | Bra | 168 | 129 | 76 | 168 | 168 | 100 |
| Total emission reductions ($tCO_2$/ha) | Moz | 90 | 127 | 106 | 90 | 165 | 137 |
| | Bra | 205 | 157 | 116 | 205 | 205 | 154 |
| Cost of $CO_2$ avoidance (€/$tCO_2$) | Moz | −61 | −43 | −14 | −61 | −33 | −11 |
| | Bra | 23 | 30 | 17 | 23 | 23 | 13 |
| Financial returns at a carbon price of 30 euros (k€/ha) | Moz | 8.2 | 9.3 | 4.7 | 8.2 | 10.5 | 5.6 |
| | Bra | 1.4 | −0.1 | 1.5 | 1.4 | 1.4 | 2.6 |

before should be included: a) which option delivers the most GHG-emission credits b) which option is cheaper or delivers the highest economic benefits, but also c) other factors might be important in decision making.

Two factors turned out to play a major role in question a): 1) sequestration or carbon losses as a result of land use change and 2) the difference in the emissions in the reference energy systems and the biomass systems. The first factor is dependent on the trading system used. Carbon changes related to land-use change can currently only be included in emission credit trading. The second factor, can vary per country, per energy system and thus per individual case. Therefore, no hard conclusions can be drawn here.

b) We found that the cheapest trading system to reduce GHG-emission depends mainly on the amount of GHG-emission that can be avoided in the exporting or importing country since both bio- and fossil transportation fuel prices are world market prices if transportation costs are low.

Among other factors c) that play a role in decision making are, diversification of energy sources, logistical capacities, domestic market protection, enhancing sustainable development, job creation and policies and regulations that are already in place. All other things being equal, physical trading could be the preferred trading alternative, because with the same amount of money and emission credits, one can also benefit from the energy. Further advantages are the diversification in energy sources and possible job creation. Besides, current policies aim at increasing the share of renewables and biomass in particular. The Netherlands, with Rotterdam as one of largest harbours of the world, would be an optimal suited country to invest in large-scale conversion facilities for biomass, thereby becoming a major player in physical biomass trading. Physical trading could also, in addition to CDM and JI, contribute to enhance development in developing countries. Poorer countries could benefit from the establishment of a global biomass market that can provide consistent demands and generate considerable income sources for these countries. We conclude that physical trading could be the most desirable trading option for biomass, unless emission reductions can be much higher in the country of biomass origin (as a result of higher emissions in the reference energy system or lower emissions in the bio-fuel project). A solution has to be found, however, to account for the carbon effects of direct and indirect land-use changes (see also Lewandowski and Faaij 2006; Fargione et al. 2008; Searchinger et al. 2008). Starting points for addressing this key issue lay in developing integrated land-use policies and management strategies that address total land-use in a region. The most important component of such a strategy is that development of bioenergy crop production is done in balance with improvements of management of agriculture and livestock management. This could be an important element for future certification systems currently widely discussed for biofuel production

The case studies all concern transportation fuels. This is a very critical category for CDM and it will probably become extremely important in the short term. We hope that this paper can contribute to the development of a methodology to determine GHG-impacts of bio-transportation fuel projects, related to ET, CDM and the certification of traded bio fuels.

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