



**Life Cycle Assessment of Refined Vegetable Oil and
Biodiesel from Jatropha Grown in Dakatcha
Woodlands of Kenya**





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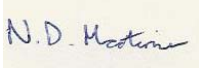
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Executive Summary

1. This project evaluates the life cycle greenhouse gas emissions associated with the proposed scheme to produce biofuels from jatropha cultivated in the Dakatcha woodlands by Kenya Jatropha Energy Ltd (100% owned by Nuove Iniziative Industriali srl of Milan, Italy) for relevant uses in Kenya and Italy. Relevant data were collected from published sources, supplemented by best interpretations where necessary details on the proposed scheme were lacking.
2. In the most likely case, it was assumed that nitrogen fertiliser, in the form of urea, would be applied at rate of 81 kg N/ha.a and irrigation would be provided at a level of 950 mm/a to support an annualised yield of 2.38 t/ha.a of dried jatropha seed. Additionally, it was assumed that a biomass-fired combined heat and power unit would provide energy for the oil extraction mill and transesterification plant.
3. An existing model, in the form of a MS Excel workbook, for biofuel production was modified to reflect these assumptions and other possible variants to generate results in the form of total greenhouse gas emissions and net savings relative to emissions from equivalent fossil fuels. Sensitivity analysis was performed to examine the effects of incorporating direct land use change, major parameters, such as the nitrogen fertiliser application rate and jatropha yield, and important assumptions, such as sources of process energy.
4. Results were compared with current and 2017 targets for net greenhouse gas emissions savings, of 35% and 50%, respectively, as part of the European Commission's sustainability criteria set out in the Renewable Energy Directive.
5. If currently uncultivated land is used for growing jatropha, it is necessary to take into account the greenhouse gas emissions from carbon stock changes due to land conversion. The effect of such direct land use change was incorporated by means of standard European Commission Guidelines and default values on the basis that land in the Dakatcha woodlands was designated as either scrubland, or dry forest with greater than 30% canopy cover, either subjected to shifting cultivation and shortened fallow or non-degraded. On this basis, it is demonstrated that proposed biodiesel production cannot achieve these saving targets with an assumed dried jatropha yield of 2.38 t/ha.a.
6. However, much higher jatropha yields appear to be expected by the developer, with the highest value cited as being 11.9 t/ha.a with irrigation. Even with this yield and assuming it refers to dried jatropha seeds with a 35% oil content, biodiesel for transport in Kenya and cogeneration in Italy cannot achieve the current saving target when the effects of direct land use are incorporated for all the categorisations of relevant land in the Dakatcha woodlands specified here.
7. Only if jatropha was cultivated on existing or abandoned agricultural land in the Dakatcha woodlands, so that direct and indirect land use change could be avoided, then both the current and 2017 emissions savings targets would be achieved for subsequent biodiesel used for transport in Kenya and cogeneration in Italy.



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1 INTRODUCTION

The potential for growing jatropha as a source of refined vegetable oil and biodiesel for energy use is attracting considerable attention throughout the world. This is mainly because jatropha is seen as a suitable oil-bearing crop which is expected to grow in relatively harsh conditions encountered in tropical and sub-tropical countries in the band of latitudes between 30°N and 35°S (Brittiane and Litaladio, 2010). In particular, jatropha is currently being proposed for large-scale cultivation in the Dakatcha woodlands of Malindi District in Kenya's Coast Province (Ebhardt and van der Westhuizen, 2010). This is part of a biofuel scheme which is being developed by Kenya Jatropha Energy Ltd which is 100% owned by Nuove Iniziative Industriali srl of Milan, Italy. There are many different driving forces behind such developments. However, one common driver is the production of alternatives to conventional energy derived from fossil fuels, principally to avoid or reduce associated greenhouse gas (GHG) emissions. The European Commission (EC) has set targets for the reduction of GHG emissions associated with the production of biofuels as part of sustainability criteria set out in its Renewable Energy Directive (RED) (EC, 2009). Hence, it is pertinent to inquire whether proposals for the production of biofuels from jatropha grown in the Dakatcha woodlands of Kenya are capable of meeting these targets for GHG emissions savings.

The aims of this project were:

- to calculate the total GHG emissions for biofuels produced from jatropha grown in the Dakatcha woodlands of Kenya, taking into account all cultivation activities, including direct land use change (dLUC), oil extraction and refining, transesterification and transportation, and
- to determine net GHG emissions savings relative to conventional fossil fuels, and compare these with targets established by the EC.

The objectives required to achieve these aims were:

- to collect relevant data on the proposed biofuel scheme in the Dakatcha woodlands of Kenya, using published literature from all suitable sources and information obtained locally by non-governmental organisations (NGOs),
- to adapt an existing MS Excel workbook for calculating total GHG emissions associated with the production of biofuels from jatropha to simulate the proposed biofuel scheme,
- to take into account the GHG emissions associated with dLUC in the Dakatcha woodlands of Kenya using standard factors provided by the EC in support of the application of the RED,
- to derive estimates of total GHG emissions, their breakdown and subsequent net GHG emissions savings, for the proposed biofuel scheme using the calculation methodology established in the RED,

- to undertake sensitivity analysis on key assumptions which can influence these results, and
- to prepare a final report which presents all main results with essential supporting information, which addresses whether the proposed biofuel scheme can achieve the net GHG emissions savings targets required by the EC, and which comments, in case such targets cannot be met, on what the developer would have to do for subsequent compliance.

2 DATA COLLECTION

Relevant information on the proposed biofuel scheme in the Dakatcha woodlands of Kenya was obtained by means of a standard literature search and through local contacts involved with NGOs. Some formal publications were identified and obtained including a feasibility study for Kenyan jatropha (Muok and Källbäck, 2008) and the Environmental Impact Assessment (EIA) Study Report for Kenya Jatropha Energy Ltd (Nzuki, Gitau and Munyao, 2009). Additionally, relevant reports from local media were accessed and specific local information was provided by ActionAid, Birdlife Europe, Nature Kenya, and the Royal Society for the Protection of Birds (RSPB). These and other sources of data were important as it was essential to obtain specific information on the key features of the biofuel scheme and on the categorisation of the land that constitutes the Dakatcha woodlands where it is intended to grow jatropha.

Unfortunately, the available information on the biofuel scheme was somewhat imprecise, vague and, in some instances, contradictory. Normally, it would be expected that the definitive details of such a development would have to be submitted in its EIA documentation as a necessary starting point for considering any realistic proposal. However, this is not the case. Fundamental aspects, such as the actual method of jatropha cultivation, the nature and scale of the oil extraction and transesterification operations, and the precise uses for the subsequent biofuel, are almost entirely missing. In particular, the levels of mechanisation, irrigation and artificial nitrogen (N) fertiliser application, if any, in jatropha cultivation are not quantified. It is unclear whether localised, small-scale oil milling or centralised, large-scale oil extraction will, in practice, be used. Additionally, only general suggestions are offered about the provision of heat and/or electricity for the oil extraction and transesterification plants. These include an apparent proposal for the anaerobic digestion (AD) of oil milling residues (possibly fruit hulls and/or jatropha press cake) to generate biogas as a means of energy supply. These and other details have a fundamental bearing on estimated total GHG emissions.

It should be noted that the EIA documentation does not quantify the total GHG emissions specifically associated with the proposed scheme. Instead, it would appear that only generalised results have been cited. In particular, an unreferenced statement claims that "...the global warming potential (sic) of the production and use of Jatropha oil is 23% of the global warming potential of fossil fuels" (Nzuki, Gitau and Munyao, 2009, p. 83). It is not apparent whether the developer is claiming that this level of GHG emissions savings will be achieved by this biofuel scheme and, if so, the basis of such a claim is not substantiated.

Given the lack of suitable information on the configuration of the proposed scheme, it has been necessary to make informed judgements about the most critical features. Based on the quoted level of annual production of 150,000 t/a of biodiesel (Ebhardt and van der Westhuizen, 2010), it seems rather unlikely that the scheme will rely on small-scale cultivation and harvesting, and manual oil extraction. Instead, typical mechanisation of agricultural practices based on current Indian experience with *jatropha* would appear to be more appropriate (Whittaker and Heath, 2009). It is stated that irrigation will be used, particularly to reach the very high *jatropha* yields quoted in the EIA documentation (see Section 6). However, the level of irrigation is not quantified. Since no information was provided on the expected N fertiliser application rate, it was decided to treat this as a variable. Similarly, the choice of methods for providing energy in the oil processing plants was addressed by means of options. These included heat from fuel oil-fired boilers and electricity imported from the Kenyan grid, and combined heat and power (CHP) units fired by fuel oil or biomass residues from the harvesting (*jatropha* prunings)¹.

Different combinations of biofuel production and use were considered. These consisted of refined vegetable oil production in Kenya for use as fuel oil either in Kenya or in Italy, and biodiesel production in Kenya either for use as a transport fuel in Kenya or as fuel oil in Italy. Although the developer has indicated that biodiesel would be produced in Kenya for use in both Kenya and Italy (Nzuki, Gitau and Munyao, 2009), it was also noted that the intended use of the exported biodiesel was for firing CHP (cogeneration) plants rather than as transport fuel (Ebhardt and van der Westhuizen, 2010). In other work (Mortimer et al, 2010), it has been indicated that the use of refined vegetable oil for electricity generation or cogeneration might be more beneficial, in terms of GHG emissions savings, as this avoids the need for transesterification. Hence, variants based on these options were included here to ensure that all potentially possible combinations of likely production and use are covered.

3 WORKBOOK MODIFICATIONS

Calculations of associated GHG emissions were undertaken using a modified version of a MS Excel workbook prepared for the Department of Energy and Climate Change in the United Kingdom (Evans, Whittaker and Mortimer, 2010). The original workbook was developed to investigate the use of different products derived from oilseed plants such as *jatropha*. The default values incorporated into this workbook attempt to reflect typical production of *jatropha* in India, as a potentially-important emerging producer of this biofuel feedstock, based on current practice reported in published sources. The key parameters and their default values in this original workbook are summarised in Table 1.

The original workbook was modified to represent the main features of production of refined vegetable oil and biodiesel in Kenya and their subsequent use in Kenya and Italy (Mortimer and Mwabonje, 2010). This involved adjusting agricultural diesel fuel

¹ The details of biogas production from the AD of oil extraction residues (fruit hulls and/or *jatropha* press cake) are not provided. Hence, it was not possible to incorporate this specific option for biomass-fired CHP into these calculations. Instead, this option was based on the direct combustion of dried *jatropha* prunings, of which there is more than sufficient for energy production.

consumption for irrigation water pumping to account for a total water requirement of 2,000 mm/a for jatropha cultivation and average rainfall of 1,050 mm/a in the Malindi district of Kenya (Brittiane and Litaladio, 2010), resulting in shortfall of 950 mm/a. In the absence of scheme specific data, it was assumed that, with this level of irrigation and a N fertiliser application rate of 81 kg N/ha.a, a yield of 2.38 t/ha.a of dried seeds with a 35% oil content would be achieved in the most likely case. Other default values in Table 1 were also adopted². Further modifications consisted of incorporating an emissions factor for grid electricity in Kenya (Carbon Trust, 2010), round trip distances of 20 km for road transport of jatropha from plantation to processing plant, 450 km for distribution of biodiesel in Kenya by road, and 16,212 km for ship transport of biodiesel from Mombasa in Kenya to Naples in Italy.

Table 1 Key Parameters and Default Values in the Original Workbook for Indian Jatropha Cultivation and Production of Refined Vegetable Oil and Biodiesel

Key Parameter	Units	Default Value	Original Source
N Fertiliser Application Rate	kg N/ha.a	81	Annualised application rate for urea; Reinhardt et al, 2008.
Irrigation Level	mm/ha.a	1115	Assumption based on shortfall in Raipur Province, India; Evans, Whittaker and Mortimer, 2010
Life Span of Jatropha Plants	a	50	Whitaker and Heath, 2008.
Annualised Sun-dried (8.5% moisture content) Seed Yield	t/ha.a	2.38	Based on an Optimised Scenario; Reinhardt et al, 2008.
Oil Content of Dried Seeds by Mass	%	35	Achten et al, 2008.
Dried Jatropha Seed to Refined Vegetable Oil Conversion Ratio	t djs/t rvo ^(a)	3.748	Derived from original workbook; Evans, Whittaker and Mortimer, 2010
Net Calorific Value of Refined Vegetable Oil	MJ/t	39,500	Whitaker and Heath, 2008.
Dried Jatropha Seed to Biodiesel Conversion Ratio	t djs/t bd ^(b)	3.945	Derived from original workbook; Evans, Whittaker and Mortimer, 2010
Net Calorific Value of Biodiesel	MJ/t	37,270	Whitaker and Heath, 2008.

Notes

- (a) Ratio of tonnes of dried jatropha seed to tonnes of refined vegetable oil.
(b) Ratio of tonnes of dried jatropha seed to tonnes of biodiesel.

² For consistency with officially published data, a net calorific value of 37,200 MJ/t was adopted for biodiesel (RFA, 2009).

4 BASIC RESULTS WITHOUT LAND USE CHANGE

The basic results, representing the most likely case for biodiesel production in the Dakatcha woodlands for use in Kenya and Italy, were derived using the modified workbook. These results³, which are consistent with the requirements of the RED methodology (EC, 2009), are summarised in Table 2 (recorded also in Mortimer and Mwabonje, 2010). This shows that the most prominent contributions to estimated total GHG emissions are soil emissions, cultivation diesel fuel and esterification, which together account for over ⅓ of the total. The soil emissions consist of nitrous oxide and carbon dioxide released from urea, applied as N fertiliser, based on Tier 1 default values published by the Inter-governmental Panel on Climate Change (IPCC, 2006). Emissions from diesel fuel arise from consumption by farming machinery and, mainly, irrigation water pumps. The contribution from esterification is almost entirely due to the use of methanol derived from fossil fuels. It should be noted that the results shown in Table 2 assume that there is no direct land use change for jatropha cultivation and that any impact from indirect land use change is not taken into account. This would be equivalent to growing jatropha on existing or abandoned agricultural land in the Dakatcha woodlands of Kenya, if such a land use exists.

Table 2 Breakdown of Total Greenhouse Gas Emissions for Biodiesel Production in Dakatcha, Kenya: Most Likely Case without Land Use Change

Contribution	Total Greenhouse Gas Emissions			
	Biodiesel from Plant with Biomass-fired CHP Unit for Use in Kenya		Biodiesel from Plant with Biomass-fired CHP Unit for Use in Italy	
	kg eq. CO ₂ /MJ	%	kg eq. CO ₂ /MJ	%
Cultivation - soil emissions	0.01110	29.9	0.01110	27.1
Cultivation - diesel fuel ^(a)	0.00933	25.1	0.00933	22.8
Cultivation - K fertiliser	0.00272	7.3	0.00272	6.6
Cultivation - N fertiliser ^(b)	0.00224	6.0	0.00224	5.5
Cultivation - electricity ^(c)	0.00154	4.1	0.00154	3.8
Cultivation - P fertiliser	0.00114	3.0	0.00114	2.8
Cultivation - other	0.00035	0.9	0.00035	0.8
Transport to Plant	0.00003	0.1	0.00003	0.1
Oil Extraction	0.00007	0.2	0.00007	0.2
Oil Refining	0.00006	0.2	0.00006	0.1
Esterification	0.00819	22.0	0.00819	20.0
Electricity Sales ^(d)	-0.00001	-	-0.00001	-
Local Transport	0.00043	1.2	0.00043	1.0
Overseas Transport	0	0	0.00377	9.2
Totals	0.03718	100.0	0.04095	100.0

Notes

- (a) Diesel fuel for use in agricultural machinery and irrigation water pumps.
- (b) Urea.
- (c) Electricity for all plantation use.
- (d) Surplus electricity sales to grid.

³ Results for estimated total greenhouse gas emissions are given in terms of kg of equivalent carbon dioxide (eq. CO₂) per unit energy, measured in mega joules (MJ), in biodiesel, based on its net calorific value, and account for carbon dioxide emissions, methane (CH₄) emissions, converted with a global warming potential (GWP) of 23 kg eq. CO₂/kg CH₄, and nitrous oxide (N₂O) emissions, converted with a GWP of 296 kg eq. CO₂/kg N₂O based on the IPCC Third Assessment Report (IPCC, 2001) and consistent with the RED methodology (EC, 2009).

These results must be set in the context of EC policy as established in the RED. This involves evaluating net GHG emissions savings, which consist of the percentage reduction in total GHG emissions of a biofuel relative to those of an equivalent conventional fuel derived from a fossil fuel⁴. The net GHG emissions savings depend on numerous considerations. These include the specific end use of the biofuel and the subsequent “fossil fuel comparator”, which consists of the total GHG emissions of the conventional fossil fuel that the biofuel replaces. In this particular instance, the end uses considered consisted of refined vegetable oil used for electricity generation in Kenya and cogeneration in Italy, respectively, and biodiesel used for transport in Kenya and cogeneration in Italy. These last two options were regarded as the most likely end use applications.

The RED provides values for fossil fuel comparators relevant to the supply of biofuels into the European Union (EU), from sources both internally and externally (EC, 2009, Annex V, Pages 55 and 56). The current fossil fuel comparator for EU electricity generation is 0.0910 kg eq. CO₂/MJ, for EU cogeneration is 0.0850 kg eq. CO₂/MJ, and for EU transport is 0.0838 kg eq. CO₂/MJ. Whilst such comparators are intended to be relevant to the EU, in the absence of similar data, these were also used, where necessary, for biofuel use in Kenya⁵.

On this basis, net GHG emissions savings were derived for the production of biofuels from jatropha obtained from the Dakatcha woodlands and results are summarised in Table 3. Such results must be compared with the minimum net GHG emissions savings required by the EC for biofuels. Currently, biofuels must achieve at least 35% savings, rising to 50% by 1 January 2017 (EC, 2009, Article 17, Page 36). It can be seen that estimated net GHG emissions savings for all the results in Table 3 meet the current target, assuming no dLUC or indirect land use change (iLUC). Additionally, all variants reach the 2017 target for savings, apart from Kenyan transport biodiesel obtained from a plant with a fuel oil-fired boiler and grid electricity and Italian cogeneration biodiesel obtained from plants with either a fuel oil-fired boiler and grid electricity, or a fuel oil-fired CHP unit. However, these are less likely options for the proposed scheme.

It should be recalled that all these basic results exclude any GHG emissions due to land use change. Hence, these conclusions only apply strictly to instances in which jatropha is grown on existing or abandoned agricultural land in the Dakatcha woodlands of Kenya, if such land use exists. Additionally, it should be noted that, if it is intended to grow jatropha on existing agricultural land, dLUC will be avoided. Instead, indirect land use change (iLUC) may have to be taken into account although the method for accommodating this within the context of EC biofuels regulation has not been agreed and disseminated at present.

⁴ Mathematically,

$$S_p = \frac{(G_a - G_b)}{G_b} \times 100\%$$

S_p = Percentage net GHG emissions savings of a biofuel (%)

G_a = Total GHG emissions of a conventional fuel (kg eq. CO₂/MJ)

G_b = Total GHG emissions of a biofuel (kg eq. CO₂/MJ)

⁵ It is expected that specific comparators for Kenya would not be very different from those adopted for the EU.

Table 3 Net Greenhouse Gas Emissions Savings for Refined Vegetable Oil and Biodiesel Based on Basic Results (without Direct Land Use Change)

Product and Application	Net Greenhouse Gas Emissions Saving ^(a) (%)		
	Plant with Fuel Oil-fired Boiler and Grid Electricity	Plant with Fuel Oil-fired CHP Unit	Plant with Biomass-fired CHP Unit
Refined Vegetable Oil for Electricity Generation in Kenya	65 ^(b)	72 ^(b)	65 ^(b)
Refined Vegetable Oil for Cogeneration in Italy	58 ^(c)	65 ^(c)	65 ^(c)
Biodiesel for Transport in Kenya	44 ^(d)	51 ^(d)	56 ^(d)
Biodiesel for Cogeneration in Italy	41 ^(c)	47 ^(c)	52 ^(c)

Notes

- (a) Assuming urea application of 81 kg N/ha.a and a yield of 2.38 t/ha.a of dried seeds with an oil content of 35%.
- (b) Net greenhouse gas emissions saving relative to 0.0910 kg eq. CO₂/MJ for fuel used in electricity generation.
- (c) Net greenhouse gas emissions saving relative to 0.0850 kg eq. CO₂/MJ for fuel used in cogeneration.
- (d) Net greenhouse gas emissions saving relative to 0.0838 kg eq. CO₂/MJ for diesel used in transport.

5 DIRECT LAND USE CHANGE

A standard procedure and default values are available from the EC for estimating the GHG emissions associated with the conversion of previously-uncultivated land to the production of biofuel crops (EC, 2009; EC, 2010). The procedure accounts for estimated changes in carbon stocks in below and above ground biomass for a given area of land and spreads these equally over a 20 year time period. The factors used to estimate carbon stock changes consist of the climate region, soil type, current land categorisation, and basic aspects of the new land use based on the type of biofuel crop. Precise specification of these factors for the Dakatcha woodlands of Kenya were not available but, using local information, it was possible to deduce the most likely interpretations of these factors. The full scope of possible interpretations of these factors for the Dakatcha woodlands, along with complete details for the calculation of net carbon stock changes resulting from dLUC are presented in Appendix A.

Based on map data and local information, it was assumed that the climate region can best be represented by “tropical, dry” and the soil type consists of “high activity clay soils”. Within the context of these calculations, the most significant consideration is the current land categorisation. It was noted that there are similarities between the Dakatcha woodlands and the *Brachystegia* and *Cynometra* forests within the Arabuko-Sokoke forest of coastal Kenya, for which an evaluation of carbon stocks has been performed (Glenday, 2008). Additionally, it has been stated that “All visitors to Dakatcha describe it as a forest not woodland. The cover is definitely above 40% so Dakatcha is a forest. Structurally, Dakatcha woodland is comparable to the *Brachystegia* woodland and the *Cynometra* forest but not mixed forest in Arabuko-Sokoke Forest. Assuming similar degradation levels for the habitats, the carbon levels

would be the same. However, Dakatcha would probably be more degraded as many parts of the woodland have farms and homes. If the uncultivated areas are assessed, the carbon levels might approximate that of Arabuko-Sokoke Forest” (Matiku and Byron, 2011).

On this basis, it was decided that, in order to address all possible interpretations of the land categorisation of the Dakatcha woodlands, three options would be considered in subsequent calculations within the context of the EC Guidelines (EC, 2010). The first option, that might represent the low point of the range of net carbon stock changes, was assumed to be “scrubland” which is defined as “land with vegetation composed largely of woody plants lower than 5 m not having clear physiognomic aspects of trees” (EC, 2010). The second option, that might represent the intermediate point in the range of net carbon stock changes, was assumed to be “forest with greater than 30% canopy cover subjected to shifting cultivation and shortened fallow” (EC, 2010). The third option, that might represent the high point in the range of net carbon stock changes, was assumed to be “non-degraded forest with greater than 30% canopy cover” (EC, 2010). In contrast, the assumptions about the type of land management and input intensity for jatropha, which is specified as a “perennial crop”, have relatively negligible influence on the net carbon stock changes calculations resulting from dLUC. The relevant dLUC factors and default values adopted for the Dakatcha woodlands of Kenya are summarised in Table 4.

Table 4 Summary of Direct Land Use Change Factors and Default Values for Dakatcha Woodland in Kenya

dLUC Factors	Interpretation for Dakatcha Woodlands, Kenya		
	African Dry Scrubland	African Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow	African Non-degraded Dry Forest with Greater than 30% Canopy Cover
Climate Region	Tropical, Dry	Tropical, Dry	Tropical, Dry
Soil Type	High Activity, Clay Soils	High Activity, Clay Soils	High Activity, Clay Soils
Total Carbon Stock Before Cultivation (t C/ha)	84.00	101.32	115.00
Biofuel Crop Type	Perennial	Perennial	Perennial
Biofuel Crop Land Management	Full Tillage	Full Tillage	Full Tillage
Biofuel Crop Input Intensity	Medium Input	Medium Input	Medium Input
Total Carbon Stock With Cultivation (t C/ha)	55.50	55.50	55.50
Net Change in Total Carbon Stock (t C/ha)	+28.50	+45.82	+59.50
Greenhouse Gas Emissions from Direct Land Use Change (kg eq. CO ₂ /ha.a)	+5,221	+8,394	+10,900

Subsequent estimates of total GHG emissions and net GHG emissions savings for biofuels derived from jatropha in the Dakatcha woodlands of Kenya with dLUC are illustrated in Tables 5 and 6, respectively (recorded also in Mortimer and Mwabonje,

2011a). Table 6 shows that, for the basic results which assume an annualised dried seed yield of 2.38 t/ha.a, net GHG emissions savings are significantly negative in all instances. This means that biofuels produced from this particular source have higher total GHG emissions than their fossil fuel alternatives. The principal reason for this is that substantial GHG emissions from the destruction of carbon stocks during conversion from either scrubland, or dry forest with greater than 30% canopy cover, subjected to shifting cultivation and shortened fallow, or undegraded, are spread over a relatively small output of biofuels resulting from the assumed yield of jatropha.

Table 5 Total Greenhouse Gas Emissions for Refined Vegetable Oil and Biodiesel Based on Basic Results (with Direct Land Use Change)

Product and Application	Original Land Categorisation	Total Greenhouse Gas Emissions ^(a) (kg eq. CO ₂ /MJ)		
		Plant with Fuel Oil-fired Boiler and Grid Electricity	Plant with Fuel Oil-fired CHP Unit	Plant with Biomass-fired CHP Unit
Refined Vegetable Oil for Electricity Generation in Kenya	African Dry Scrubland	0.2402	0.2341	0.2347
	African Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow	0.3667	0.3606	0.3611
	African Non-degraded Dry Forest with Greater than 30% Canopy Cover	0.4666	0.4605	0.4611
Refined Vegetable Oil for Cogeneration in Italy	African Dry Scrubland	0.2437	0.2376	0.2382
	African Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow	0.3702	0.3641	0.3647
	African Non-degraded Dry Forest with Greater than 30% Canopy Cover	0.4701	0.4640	0.4646
Biodiesel for Transport in Kenya	African Dry Scrubland	0.2792	0.2738	0.2698
	African Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow	0.4206	0.4152	0.4111
	African Non-degraded Dry Forest with Greater than 30% Canopy Cover	0.5322	0.5267	0.5228
Biodiesel for Cogeneration in Italy	African Dry Scrubland	0.2862	0.2775	0.2735
	African Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow	0.4244	0.4189	0.4150
	African Non-degraded Dry Forest with Greater than 30% Canopy Cover	0.5361	0.5306	0.5267

Notes

(a) Assuming urea application of 81 kg N/ha.a and a yield of 2.38 t/ha.a of dried seeds with an oil content of 35%, and including greenhouse gas emissions from dLUC.

Table 6 Net Greenhouse Gas Emissions Savings for Refined Vegetable Oil and Biodiesel Based on Basic Results (with Direct Land Use Change)

Product and Application	Original Land Categorisation	Net Greenhouse Gas Emissions Saving ^(a) (%)		
		Plant with Fuel Oil-fired Boiler and Grid Electricity	Plant with Fuel Oil-fired CHP Unit	Plant with Biomass-fired CHP Unit
Refined Vegetable Oil for Electricity Generation in Kenya	African Dry Scrubland	-164 ^(b)	-157 ^(b)	-158 ^(b)
	African Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow	-303 ^(b)	-296 ^(b)	-297 ^(b)
	African Non-degraded Dry Forest with Greater than 30% Canopy Cover	-413 ^(b)	-406 ^(b)	-407 ^(b)
Refined Vegetable Oil for Cogeneration in Italy	African Dry Scrubland	-187 ^(c)	-180 ^(c)	-180 ^(c)
	African Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow	-336 ^(c)	-328 ^(c)	-329 ^(c)
	African Non-degraded Dry Forest with Greater than 30% Canopy Cover	-453 ^(c)	-446 ^(c)	-447 ^(c)
Biodiesel for Transport in Kenya	African Dry Scrubland	-233 ^(d)	-227 ^(d)	-222 ^(d)
	African Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow	-402 ^(d)	-394 ^(d)	-391 ^(d)
	African Non-degraded Dry Forest with Greater than 30% Canopy Cover	-535 ^(d)	-529 ^(d)	-524 ^(d)
Biodiesel for Cogeneration in Italy	African Dry Scrubland	-237 ^(c)	-227 ^(c)	-222 ^(c)
	African Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow	-399 ^(c)	-393 ^(c)	-388 ^(c)
	African Non-degraded Dry Forest with Greater than 30% Canopy Cover	-536 ^(c)	-524 ^(c)	-520 ^(c)

Notes

- (a) Assuming urea application of 81 kg N/ha.a and a yield of 2.38 t/ha.a of dried seeds with an oil content of 35%, and including greenhouse gas emissions from dLUC.
- (b) Net greenhouse gas emissions saving relative to 0.0910 kg eq. CO₂/MJ for fuel used in electricity generation.
- (c) Net greenhouse gas emissions saving relative to 0.0850 kg eq. CO₂/MJ for fuel used in cogeneration.
- (d) Net greenhouse gas emissions saving relative to 0.0838 kg eq. CO₂/MJ for diesel used in transport.

6 SENSITIVITY ANALYSIS

It will be appreciated from the previous results that the most influential parameter in the assessment of net GHG emissions savings when dLUC is taken into account is jatropha yield. Consequently, the effect of varying yield was investigated using the modified workbook as part of sensitivity analysis (recorded in Mortimer and Mwabonje, 2011b). In particular, this parameter was varied over a theoretical range to determine the minimum jatropha yield required to achieve the current EC target for net GHG emissions savings of 35% from the relevant application of subsequent biofuels⁶. Subsequent variations are summarised in Appendices B to E for the production of refined vegetable oil for electricity generation in Kenya and for cogeneration in Italy, and biodiesel for transport in Kenya and cogeneration in Italy, respectively. Results are summarised in Table 7.

Strictly speaking, this sensitivity analysis should incorporate the response curve for jatropha which represents the variation of yield with the main agricultural input factor, such as N fertiliser or water. However, reliable response curves for jatropha are currently not available, either in general form or specifically for the Dakatcha woodlands of Kenya (Brittiane and Lutaladio, 2010). Hence, it was assumed that all values of yield included in the range examined here could be achieved with fixed values of N fertiliser (either 81 kg N/ha.a or 0 kg N/ha.a) and irrigation (950 mm/a). These are somewhat simplistic and, in fact, over-optimistic assumptions that are favourable to the evaluation of net GHG emissions savings of biofuels derived from jatropha. In practice, the form of a response curve would mean that these savings would rise as the N fertiliser application rate and/or level of irrigation increase until a maximum value is reached after which savings decline. From earlier work with other biofuels crops, it is known that maximum net GHG emissions savings do not necessarily coincide with optimum economic yield (Mortimer and Elsayed, 2006).

⁶ It must be emphasised that the extreme high values in the full yield range adopted here for necessary calculation purposes are well beyond maximum yield values recorded for actual jatropha cultivation.

Table 7 Required Minimum Jatropha Yield for Net Greenhouse Gas Emissions Saving Targets

Land Use Change	Product and Application	Required Minimum Jatropha Yield ^(a) (t/ha.a)					
		Fixed N Fertiliser Application Rate ^(b)			Zero N Fertiliser Application Rate ^(c)		
		Plant with Fuel Oil-fired Boiler and Grid Electricity	Plant with Fuel Oil-fired CHP Unit	Plant with Biomass-fired CHP Unit	Plant with Fuel Oil-fired Boiler and Grid Electricity	Plant with Fuel Oil-fired CHP Unit	Plant with Biomass-fired CHP Unit
No Direct Land Use Change	Vegetable Oil for Electricity in Kenya	1.2	1.0	1.0	<1.0	<1.0	<1.0
	Vegetable Oil for Cogeneration in Italy	1.4	1.2	1.2	<1.0	<1.0	<1.0
	Biodiesel Used for Transport in Kenya	1.8	1.6	1.6	1.0	<1.0	<1.0
	Biodiesel Used for Cogeneration in Italy	2.0	1.6	1.6	1.0	<1.0	<1.0
Conversion from African Dry Scrubland	Vegetable Oil for Electricity in Kenya	9.0	8.8	8.8	9.5	8.6	8.6
	Vegetable Oil for Cogeneration in Italy	11.8	10.3	10.3	11.0	9.7	9.7
	Biodiesel Used for Transport in Kenya	16.0	14.1	13.0	15.6	13.5	12.4
	Biodiesel Used for Cogeneration in Italy	17.9	15.2	13.7	17.1	14.5	13.3
Conversion from African Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow	Vegetable Oil for Electricity in Kenya	15.8	14.3	14.3	15.2	13.9	13.9
	Vegetable Oil for Cogeneration in Italy	18.6	16.4	16.4	18.0	16.2	16.2
	Biodiesel Used for Transport in Kenya	25.9	22.6	21.0	25.3	22.0	20.0
	Biodiesel Used for Cogeneration in Italy	28.1	24.4	22.2	27.7	23.6	21.4
Conversion from African Non-degraded Dry Forest with Greater than 30% Canopy Cover	Vegetable Oil for Electricity in Kenya	19.4	17.5	17.5	19.4	17.1	17.1
	Vegetable Oil for Cogeneration in Italy	22.9	20.2	20.4	22.3	19.4	20.0
	Biodiesel Used for Transport in Kenya	32.4	27.8	25.5	31.2	27.0	25.1
	Biodiesel Used for Cogeneration in Italy	34.7	30.0	27.4	34.3	29.3	26.7

Notes

(a) Harvested dried seed with 35% oil content and a net greenhouse gas emissions savings target of 35% for refined vegetable oil or biodiesel.

(b) Variable yield with fixed urea application rate of 81 kg N/ha.a.

(c) Variable yield with zero urea application rate.

 Required minimum yield greater than highest expected value for jatropha cultivation in the Dakatcha woodlands of Kenya (see Table 8)

 Required minimum yield equal to or less than highest expected value for jatropha cultivation in the Dakatcha woodlands of Kenya (see Table 8)

Table 7 shows the minimum jatropha yield that must be realised to achieve net GHG emissions savings of at least 35% for biofuel produced from the Dakatcha woodlands of Kenya, with different fixed N fertiliser application rates, both without and with dLUC, and using different process energy sources, with biofuel used in different applications. Not surprisingly, the lowest minimum jatropha yields are required when no dLUC occurs or is taken into account. These yields (< 2.0 t/ha.a) are less than the default value adopted for calculating the basic results (2.38 t/ha.a).

The minimum yields are much higher when the effects of dLUC are incorporated. These may be compared with the published values of expected jatropha yield from the Dakatcha woodlands of Kenya (Nzuki, Gitau and Munyao, 2009). These values, and estimated annualised equivalents over a 50 year jatropha plant life, are illustrated in Table 8. It should be noted that the original source, which is the EIA Study Report for the proposed scheme, does not specify the nature of the expected jatropha yield clearly. In particular, quoted values are not qualified in terms of whether they refer to harvested fresh fruit or dried seed. However, it is implied that these yields consist of dried seed (Nzuki, Gitau and Munyao, 2009; p. viii) and that those with irrigation are the most relevant. Hence, annualised jatropha yields of between 5.1 and 11.9 t/ha.a seem to be expected by the developer.

Table 8 Expected Jatropha Yields and Annualised Values for the Dakatcha Woodlands of Kenya

Year	Expected Jatropha Seed Yield ^(a, b) (t/ha.a)					
	Not Irrigated			Irrigated		
	Low	Normal	High	Low	Normal	High
1	0.10	0.25	0.40	0.75	1.25	2.50
2	0.50	1.00	1.50	1.00	1.50	3.00
3	0.75	1.25	1.75	4.25	5.00	5.00
4	0.90	1.75	2.25	5.25	6.25	8.00
5	1.10	2.00	2.75	5.25	8.00	12.50
Annualised ^(c)	1.057	1.925	2.648	5.055	7.640	11.870

Notes

- (a) Yields for Years 1 to 5 based on scheme developer's data (Nzuki, Gitau and Munyao, 2009, Tables 1 and 2, Page 14).
- (b) It should be noted that the form of the jatropha seed, especially whether it is fresh (with a given moisture content) or dry (with a lower moisture content) is not entirely explicit, and the levels of rainfall and irrigation, and fertiliser application rates, are not stated in the scheme developer's data (Nzuki, Gitau and Munyao, 2009).
- (c) Assuming yields as quoted for Years 1 to 5, with subsequent yield for Years 6 to 50 constant at level of Year 5, with the resulting cumulative lifetime output divided equally over 50 years.

These expected values can be compared with the minimum yields presented in Table 6. This shows that there are only certain circumstances when the expected yields equal or exceed the minimum values required to achieve the EC target of 35% net GHG emissions savings. These particular instances refer to the production and use of refined vegetable oil rather than biodiesel, as proposed by the scheme developer. Even in these instances, the required minimum yields can only be met by the highest value

expected with irrigated jatropha cultivation and when no dLUC is occurs or dLUC consists of conversion from African dry scrubland. Conversely, all options involving the production of biodiesel for use in either Kenya or Italy are unable to reach the EC target for savings unless unrealistic values of jatropha yield are assumed (> 13.2 t/ha.a). Specifically, improbably high values of yield (> 20.0 t/ha.a) are required to achieve target savings for biodiesel production involving the conversion of dry forest with greater than 30% canopy cover to jatropha cultivation in the Dakatcha woodlands of Kenya. This is particularly poignant as it would seem that, in the proposed scheme, jatropha cultivation is most likely to occur in land formerly regarded as dry forest with greater than 30% canopy cover. It should also be noted that repeating this sensitivity analysis demonstrated that none of the options considered can achieve the higher 2017 EC RED target of 50% for net GHG emissions savings, even assuming that the yield of dried jatropha seed could reach the highest value of 11.9 t/ha.a expected with irrigation by the developer.

7 CONCLUSIONS

Based on the most favourable interpretation of published data provided by the developer of the proposed scheme to produce and use biofuels from the cultivation of jatropha in the Dakatcha woodlands of Kenya, the following conclusions can be drawn with regard to the avoidance or reduction of GHG emissions in the context of the EC RED:

- If jatropha is cultivated on land described as dry scrubland, or dry forest with greater than 30% canopy cover, either subjected to shifting cultivation with shortened fallow or non-degraded, in the Dakatcha woodland of Kenya, then EC RED targets for net GHG emissions savings cannot be achieved when a typical yield of 2.38 t/ha.a for dried jatropha seed, reflecting actual current Indian experience, is assumed.
- The current proposal for producing biodiesel, on land designated as dry scrubland, or dry forest with greater than 30% canopy cover, either subjected to shifting cultivation with shortened fallow or non-degraded, in the Dakatcha woodland of Kenya, is unable to achieve the current EC RED target of at least 35% for net GHG emissions savings for transport use in Kenya or cogeneration in Italy, even if:
 - the developer's highest expected annualised yield of 11.9 t/ha.a for dried jatropha seed is realised (with irrigation),
 - it is assumed that no N fertiliser is applied during cultivation, and
 - biomass-fired CHP is used as a source of heat and electricity for the oil extraction mill and the transesterification plant.
- The current EC RED target of 35% for net GHG emissions savings might only be achieved for electricity generation in Kenya and cogeneration in Italy, if refined vegetable oil, for fuel use, rather than biodiesel was produced from jatropha grown with the developer's highest expected annualised yield of 11.9 t/ha.a on land previously designated as dry scrubland in the Dakatcha woodlands of Kenya.
- For all possible categorisations of currently-uncultivated land in the Dakatcha woodlands of Kenya, the EC RED 2017 target of 50% for net GHG emissions

savings cannot be achieved for any realistic combination of technical options, even with the developer's highest expected annualised yield of 11.9 t/ha.a for dried jatropha seed.

- If jatropha is cultivated on existing or abandoned agricultural land in the Dakatcha woodlands of Kenya so that GHG emissions from dLUC do not arise and iLUC is avoided (assuming such land exists), then biofuels, in the form of either refined vegetable oil used for electricity generation in Kenya or cogeneration in Italy, or biodiesel for transport in Kenya or cogeneration in Italy, will achieve the current EC RED target of at least 35% for net GHG emissions savings.
- Moreover, the EC RED 2017 target of 50% for net GHG emissions savings will also be achieved in such circumstances for refined vegetable oil and for biodiesel, if a biomass-fired CHP unit is used as a source of heat and electricity for the oil extraction mill and the transesterification plant in Kenya.

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APPENDIX A: Greenhouse Gas Emissions from Direct Land Use Change

A.1 Basic Equations

The required equation for estimating total greenhouse gas (GHG) emissions from direct land use change (dLUC) is based on the annualised emissions from carbon stock changes divided equally over a specified period of 20 years (EC, 2009, Annex V, p. 54, para. 7):

$$e_l = (CS_R - CS_A) \times 3,664 \times 1/20 \times 1/P - e_B \quad (\text{Equation 1})$$

where,

e_l	=	annualised GHG emissions from carbon stock change due to land use change (kg eq. CO ₂ /MJ)
CS_R	=	carbon stock per unit area associated with the reference land use, measured as the mass of carbon per unit area, including both soil and vegetation (t C/ha)
CS_A	=	carbon stock per unit area associated with actual land use, measured as the mass of carbon per unit area, including both soil and vegetation (t C/ha)
P	=	annual productivity of the crop grown after land use change, measured in terms of the energy content of the subsequent biofuel (MJ/ha.a)
e_B	=	bonus of 27 g eq. CO ₂ /MJ for biofuel crops grown on restored degraded land

It has been assumed that the land for proposed jatropha cultivation in the Dakatcha woodlands is not considered to be degraded land. Hence, the final term, e_B , in this equation has been excluded from the following calculations.

The general equation for the calculation of the carbon stocks in land prior to conversion and after biofuel crop cultivation is based on the evaluation of the carbon in the soil and in the vegetation (EC, 2010, p. 22, para. 3):

$$CS_i = (SOC + C_{VEG}) \quad (\text{Equation 2})$$

where,

CS_i	=	carbon stock per unit area associated with land use i (t C/ha)
SOC	=	soil organic carbon stock (t C/ha)
C_{VEG}	=	above and below ground vegetation carbon stock (t C/ha)

It has been assumed that the soil in the Dakatcha woodlands is a mineral soil rather than an organic soil. Hence, the general equation for calculation of the soil organic carbon stock, SOC, is based on the standard soil organic carbon stock, and land use, land management land input factors (EC, 2010, p. 23, para. 4.1):

$$SOC = SOC_{ST} \times F_{LU} \times F_{MG} \times F_I \quad (\text{Equation 3})$$

where,

SOC	=	soil organic carbon stock (t C/ha)
SOC_{ST}	=	standard soil organic carbon stock in the 0 - 30 cm topsoil layer (t C/ha)
F_{LU}	=	land use factor reflecting the difference in soil carbon associated with the type of land use compared to the standard soil organic carbon
F_{MG}	=	management factor reflecting the difference in soil carbon associated with the principal management practice compared to the standard soil organic carbon

F_I = input factor reflecting the difference in soil carbon associated with different levels of carbon input compared to the standard soil organic carbon

It should be noted that, if current land use is not managed actively, then the management factor, F_{MG} , and input factor, F_I , are not relevant and Equation 3 is reduced to:

$$SOC = SOC_{ST} \times F_{LU} \quad (\text{Equation 4})$$

where,

SOC = soil organic carbon stock (t C/ha)
 SOC_{ST} = standard soil organic carbon stock in the 0 - 30 cm topsoil layer (t C/ha)
 F_{LU} = land use factor reflecting the difference in soil carbon associated with the type of land use compared to the standard soil organic carbon

This is the form of the equation that is relevant to current land use in the Dakatcha woodlands on the assumption that there is no significant management.

A.2 Unit Soil Organic Carbon Stock of the Dakatcha Woodlands

The standard soil organic carbon stock, SOC_{ST} , depends on the climate region and the soil type. Using global maps for climate regions (EC, 2010, p. 21, Figure 1) and soil types (EC, 2010, p. 22, Figure 2), it has been assumed that the Dakatcha woodlands of Kenya are characterised by experiencing a "tropical, dry climate", and possessing "high activity clay soils". This results in a value for the standard soil organic carbon stock of 38.0 t C/ha (EC, 2010, p. 25, Table 1).

This standard value for soil organic carbon stock has to be adjusted, by means of Equation 4, for current land use in the Dakatcha woodlands.

If the land is categorised as "tropical dry forest with shifting cultivation⁷ and mature fallow⁸", then the land use factor, F_{LU} , is taken as 0.80 (EC, 2010, p. 32, Table 7) and the soil organic carbon stock, SOC , is:

$$SOC = 38.0 \times 0.80 = 30.40 \text{ t C/ha}$$

If the land is categorised as "tropical dry forest with shifting cultivation and shortened fallow⁹", then the land use factor, F_{LU} , is taken as 0.64 (EC, 2010, p. 32, Table 7) and the soil organic carbon stock, SOC , is:

$$SOC = 38.0 \times 0.64 = 24.32 \text{ t C/ha}$$

If the land is categorised as "tropical dry native forest (non-degraded)", then the land use factor, F_{LU} , is taken as 1 (EC, 2010, p. 32, Table 7) and the soil organic carbon stock, SOC , is:

$$SOC = 38.0 \times 1 = 38.00 \text{ t C/ha}$$

⁷ This is defined as permanent shifting cultivation in which tropical forest is cleared for planting annual crops for a short period, of between 3 and 5 years, and then abandoned for regrowth (EC, 2010, p. 33, Table 8).

⁸ This is defined as representing situations where the forest vegetation recovers to a mature or near mature state prior to being cleared again for crop use (EC, 2010, p. 33, Table 8).

⁹ This is defined as representing situations where forest vegetation recovery is not attained prior to reclearing (EC, 2010, p. 33, Table 8).

If the land is categorised as “tropical dry scrubland”, then the land management factor, F_{MG} , is taken as 1 and the soil organic carbon stock, SOC, is:

$$SOC = 38.0 \times 1 = 38.0 \text{ t C/ha}$$

A.3 Unit Vegetation Carbon Stock of the Dakatcha Woodlands

The above and below ground vegetation carbon stock of African tropical dry forest, excluding forest plantations, with canopy cover between 10% and 30% is given as 14.00 t C/ha (EC, 2010, p. 35, Table 16).

The above and below ground vegetation carbon stock of African tropical dry forest, excluding forest plantations, with canopy cover greater than 30% is given as 77.00 t C/ha (EC, 2010, p. 37, Table 17).

The above and below ground vegetation carbon stock of African tropical scrubland, consisting of land with vegetation composed largely of woody plants lower than 5 m not having clear physiognomic aspects of trees, is given as 46.00 t C/ha (EC, 2010, p. 35, Table 15).

A.4 Unit Total Carbon Stock of the Dakatcha Woodlands

Using the Equation 2, a range of estimates of the unit total carbon stock, CS_R , of the Dakatcha woodlands of Kenya can be derived, depending on the assumed categorisation of the land. Estimates are summarised in Table A.1. From this, it can be seen that the possible unit total carbon stock of the Dakatcha woodlands could range from 38.32 t C/ha to 115.00 t C/ha. The nearest mid-point of this range could be represented by African tropical dry scrubland consisting of land with vegetation composed largely of woody plants lower than 5 m not having clear physiognomic aspects of trees which would have a unit total carbon stock of 84.00 t C/ha.

Table A.1 Estimates of Unit Total Carbon Stock of Dakatcha Woodlands

Land Categorisation	Unit Soil Organic Carbon Stock (t C/ha)	Unit Above and Below Ground Vegetation Carbon Stock (t C/ha)	Unit Total Carbon Stock (t C/ha)
African tropical dry forest, excluding forest plantations, with canopy cover between 10% and 30%, subjected to shifting cultivation and shortened fallow	24.32	14.00	38.32
African tropical dry forest, excluding forest plantations, with canopy cover between 10% and 30%, subjected to shifting cultivation and mature fallow	30.40	14.00	44.40
African tropical dry native (non-degraded) forest, excluding forest plantations, with canopy cover between 10% and 30%	38.00	14.00	52.00
African tropical dry scrubland consisting of land with vegetation composed largely of woody plants lower than 5 m not having clear physiognomic aspects of trees	38.00	46.00	84.00
African tropical dry forest, excluding forest plantations, with canopy cover greater than 30%, subjected to shifting cultivation and shortened fallow	24.32	77.00	101.32
African tropical dry forest, excluding forest plantations, with canopy cover greater than 30%, subjected to shifting cultivation and mature fallow	30.40	77.00	107.40
African tropical dry native (non-degraded) forest, excluding forest plantations, with canopy cover greater than 30%	38.00	77.00	115.00

A.5 Unit Soil Organic Carbon Stock of Possible Jatropha Cultivation in the Dakatcha Woodlands

The soil organic carbon stock of jatropha cultivation in the Dakatcha woodlands of Kenya can be estimated by using Equation 3 to adjust the assumed standard soil organic carbon stock of 38.0 t C/ha for “tropical dry climate” and “high activity clay soils” (EC, 2010, p. 25, Table 1). Based on the basic description of proposed cultivation practices (Nzuki, Gitau and Munyao, 2009) in a “tropical dry climate”, the relevant land use factor, F_L , is 1 for a “perennial crop”, such as jatropha, as a “multi-annual crop whose stems are not annually harvested” (EC, 2010, p. 29, Table 4), the land management factor, F_{MG} , is 1 for “full tillage” in which “substantial soil disturbance with full inversion occurs during planting” (EC, 2010, p. 29, Tables 3 and 4), and “medium input” cultivation is employed in which “residues are returned to the fields” (EC, 2010, p. 29, Tables 3 and 4). This results in a soil organic carbon stock, SOC, for jatropha cultivation in the Dakatcha woodlands of:

$$\text{SOC} = 38.0 \times 1 \times 1 \times 1 = 38.00 \text{ t C/ha.}$$

This indicates that the soil organic carbon stock is expected to remain unchanged when jatropha is cultivated in the Dakatcha woodlands.

A.6 Unit Vegetation Carbon Stock of Possible Jatropha Cultivation in the Dakatcha Woodlands

The above and below ground vegetation carbon stock of jatropha cultivation is given as 17.50 t C/ha (EC, 2010, p. 34, Table 12).

A.7 Unit Total Carbon Stock of Possible Jatropha Cultivation in the Dakatcha Woodlands

Using Equation 2, the unit total carbon stock, CS_A , of jatropha cultivation in the Dakatcha woodlands of Kenya is estimated to be $38.00 + 17.50 \text{ t C/ha} = 55.50 \text{ t C/ha}$.

A.8 Net Change in Unit Total Carbon Stock by Possible Jatropha Cultivation in the Dakatcha Woodlands

Estimates of the net change in unit total carbon stock, $CS_R - CS_A$, by possible jatropha cultivation in the Dakatcha woodlands of Kenya are summarised in Table A.2. It can be seen that the estimated net change in the unit total carbon stock can range from -17.18 t C/ha to +59.50 t C/ha. It should be noted that negative values represent an increase in the total carbon stock with a net absorption of CO_2 by dLUC to jatropha cultivation. Positive values represent a decrease in the total carbon stock causing a net emission of CO_2 by dLUC to jatropha cultivation. The nearest mid-point value of this range could be represented by African tropical dry scrubland consisting of land with vegetation composed largely of woody plants lower than 5 m not having clear physiognomic aspects of trees which would have a net change in the unit total carbon stock of +28.50 t C/ha.

Table A.2 Estimates of the Net Change in Unit Total Carbon Stock by Possible
Jatropha Cultivation in Dakatcha Woodlands

Land Categorisation	Unit Total Carbon Stock Before Cultivation (t C/ha)	Unit Total Carbon Stock After Cultivation (t C/ha)	Net Change in Unit Total Carbon Stock (t C/ha)
African tropical dry forest, excluding forest plantations, with canopy cover between 10% and 30%, subjected to shifting cultivation and shortened fallow	38.32	55.50	-17.18
African tropical dry forest, excluding forest plantations, with canopy cover between 10% and 30%, subjected to shifting cultivation and mature fallow	44.40	55.50	-11.10
African tropical dry native (non-degraded) forest, excluding forest plantations, with canopy cover between 10% and 30%	52.00	55.50	-3.50
African tropical dry scrubland consisting of land with vegetation composed largely of woody plants lower than 5 m not having clear physiognomic aspects of trees	84.00	55.50	+28.50
African tropical dry forest, excluding forest plantations, with canopy cover greater than 30%, subjected to shifting cultivation and shortened fallow	101.32	55.50	+45.82
African tropical dry forest, excluding forest plantations, with canopy cover greater than 30%, subjected to shifting cultivation and mature fallow	107.40	55.50	+51.90
African tropical dry native (non-degraded) forest, excluding forest plantations, with canopy cover greater than 30%	115.00	55.50	+59.5

A.9 Contribution of Direct Land Use Change to Total Greenhouse Gas Emissions

Evaluation of the contribution of direct land use change to the total GHG emissions of biofuels derived from jatropha cultivated in the Dakatcha woodlands of Kenya depends on the productivity, P , as indicated by Equation 1. In turn, this is determined by the yield of the jatropha, the ratio for conversion of dried jatropha seed (jds) to the biofuel produced from it and the net calorific value of this biofuel. For the basic results, it has been assumed that the yield is 2.38 t/ha.a of dried jatropha seeds. In the case of producing refined vegetable oil (rvo) as a potential fuel, the conversion ratio is 3.748 t djs/t rvo and the net calorific value is 39,500 MJ/t rvo. Hence, the productivity, P , for refined vegetable oil used as a fuel is:

$$P = 2.38 \times (1/3.748) \times 39,500 = 25,083 \text{ MJ/ha.a}$$

In the case of producing biodiesel (bd), the conversion ratio is 3.945 t djs/t bd and the net calorific value is 37,270 MJ/t bd. Hence, the productivity, P, for refined vegetable oil used as a fuel is:

$$P = 2.38 \times (1/3.945) \times 37,270 = 22,485 \text{ MJ/ha.a}$$

The estimated contributions of dLUC to total GHG emissions of refined vegetable oil, used as a fuel, and biodiesel derived from possible jatropha cultivation in the Dakatcha woodlands are summarised in Tables A.3 and A.4, respectively. Negative values of these contributions represent net absorption of CO₂ by dLUC, whilst positive values represent a net emission of CO₂. To obtain a perspective on these estimates, they can be compared with the total GHG emissions associated with diesel derived from conventional crude oil and used for transport of 0.0838 kg eq. CO₂/MJ, the total GHG emissions associated with fuel oil derived from conventional crude oil and used in cogeneration of 0.0850 kg eq. CO₂/MJ for, and the total GHG emissions associated with fuel oil used in electricity generation of 0.0910 kg eq. CO₂/MJ (EC, 2010; Annex V, para. 19, p. 55 – 56). Comparison show that all those land categories in which dLUC makes a positive contribution to total GHG emissions will result in biofuels that exceed their fossil fuel comparators.

Table A.3 Contribution of Direct Land Use Change to Total Greenhouse Gas Emissions of Refined Vegetable Oil for Fuel Use from Possible Jatropha Cultivation in Dakatcha Woodlands

Land Categorisation	Contribution to Total Greenhouse Gas Emissions (kg eq. CO ₂ /MJ)
African tropical dry forest, excluding forest plantations, with canopy cover between 10% and 30%, subjected to shifting cultivation and shortened fallow	-0.1255
African tropical dry forest, excluding forest plantations, with canopy cover between 10% and 30%, subjected to shifting cultivation and mature fallow	-0.0811
African tropical dry native (non-degraded) forest, excluding forest plantations, with canopy cover between 10% and 30%	-0.0256
African tropical dry scrubland consisting of land with vegetation composed largely of woody plants lower than 5 m not having clear physiognomic aspects of trees	+0.2082
African tropical dry forest, excluding forest plantations, with canopy cover greater than 30%, subjected to shifting cultivation and shortened fallow	+0.3347
African tropical dry forest, excluding forest plantations, with canopy cover greater than 30%, subjected to shifting cultivation and mature fallow	+0.3791
African tropical dry native (non-degraded) forest, excluding forest plantations, with canopy cover greater than 30%	+0.4346

Table A.4 Contribution of Direct Land Use Change to Total Greenhouse Gas Emissions of Biodiesel from Possible Jatropha Cultivation in Dakatcha Woodlands

Land Categorisation	Contribution to Total Greenhouse Gas Emissions (kg eq. CO ₂ /MJ)
African tropical dry forest, excluding forest plantations, with canopy cover between 10% and 30%, subjected to shifting cultivation and shortened fallow	-0.1400
African tropical dry forest, excluding forest plantations, with canopy cover between 10% and 30%, subjected to shifting cultivation and mature fallow	-0.0904
African tropical dry native (non-degraded) forest, excluding forest plantations, with canopy cover between 10% and 30%	-0.0285
African tropical dry scrubland consisting of land with vegetation composed largely of woody plants lower than 5 m not having clear physiognomic aspects of trees	+0.2322
African tropical dry forest, excluding forest plantations, with canopy cover greater than 30%, subjected to shifting cultivation and shortened fallow	+0.3740
African tropical dry forest, excluding forest plantations, with canopy cover greater than 30%, subjected to shifting cultivation and mature fallow ¹⁰ -	+0.4229
African tropical dry native (non-degraded) forest, excluding forest plantations, with canopy cover greater than 30%	+0.4848

APPENDIX B: Dakatcha Refined Vegetable Oil Production and Use for Electricity Generation in Kenya

Results generated from RSPBKenya_jat_v6.xls and recorded in RSPB Kenya Biofuels GHG dLUC 04.xls with the following assumptions:

Dried jatropha seed oil content = 35%

Jatropha conversion ratio = 3.748 t dried jatropha seed/t refined vegetable oil

Net calorific value of refined vegetable oil = 39,500 MJ/t

Figure B.1 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Electricity Production in Kenya Produced from Jatropha with Yield: Conversion from Scrubland, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction

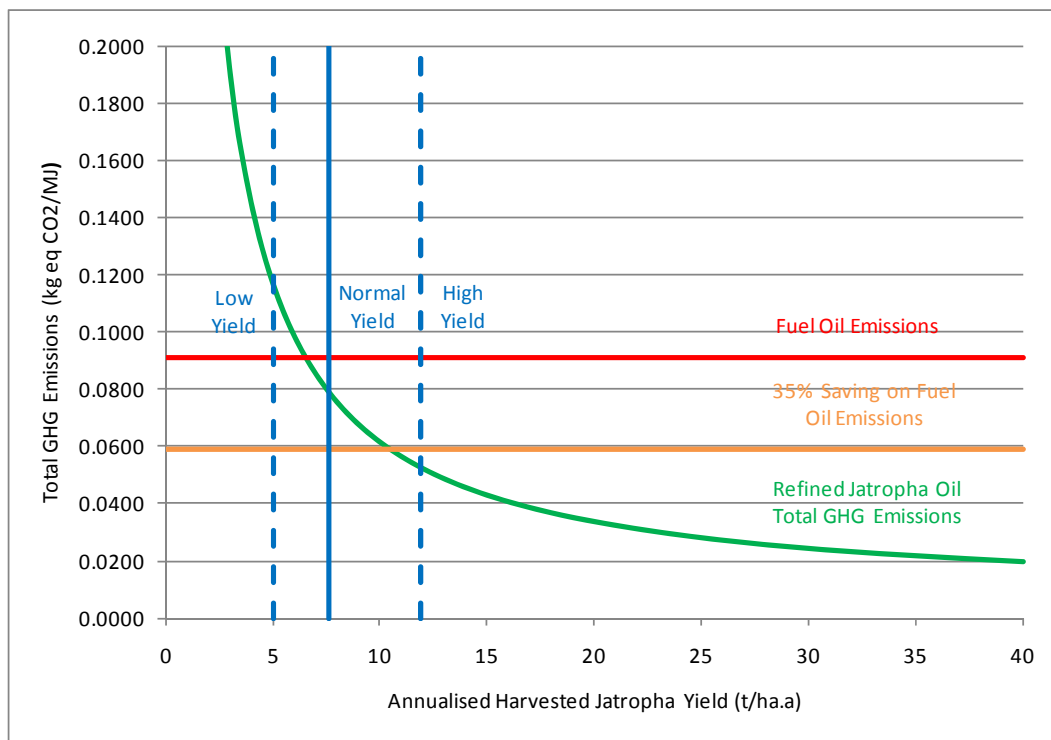


Figure B.2 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Electricity Production in Kenya Produced from Jatropha with Yield: Conversion from Scrubland, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction

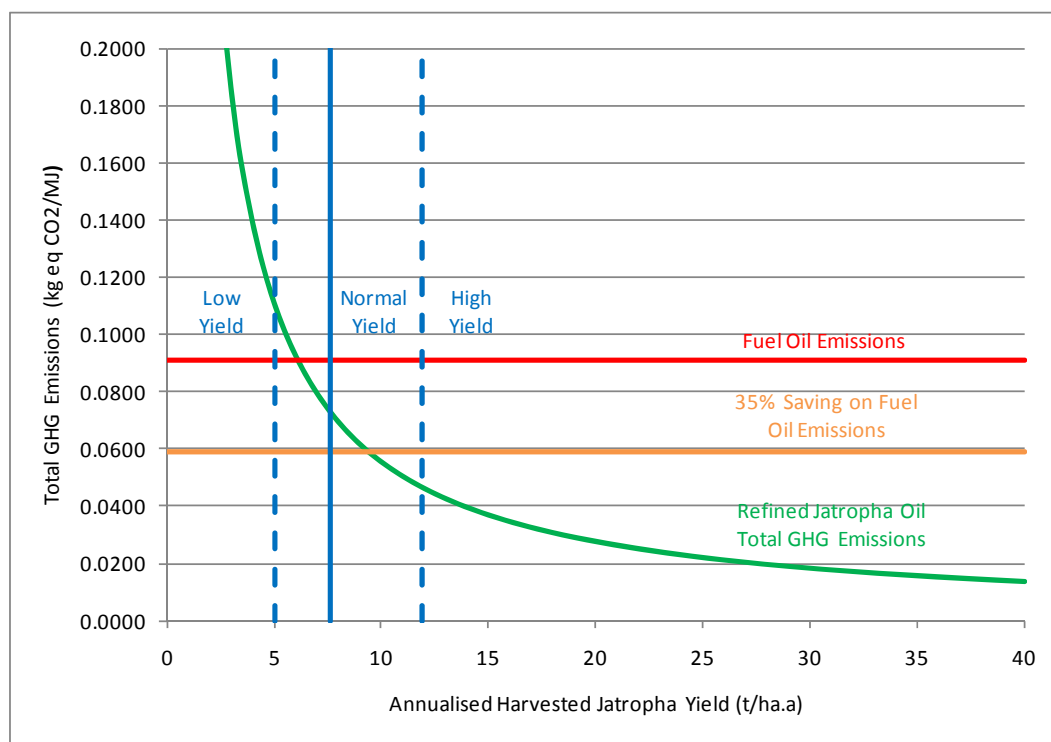


Figure B.3 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Electricity Production in Kenya Produced from Jatropha with Yield: Conversion from Scrubland, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Biomass-fired Combined Heat and Power Unit for Oil Extraction

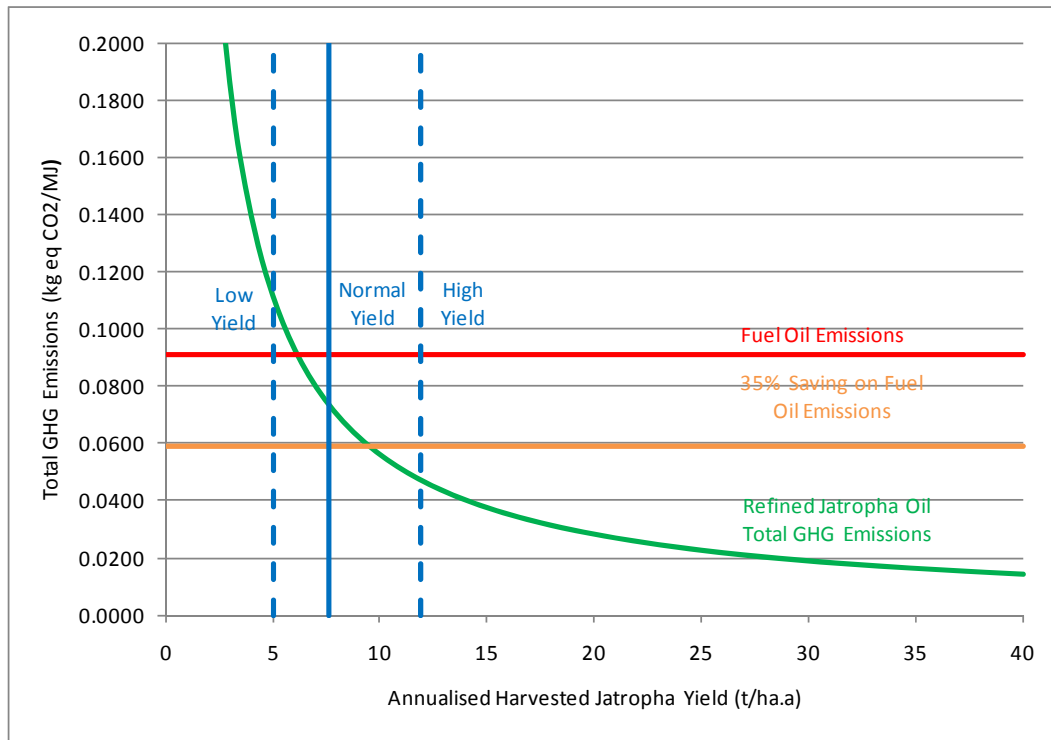


Figure B.4 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Electricity Production in Kenya Produced from Jatropha with Yield: Conversion from Scrubland, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction

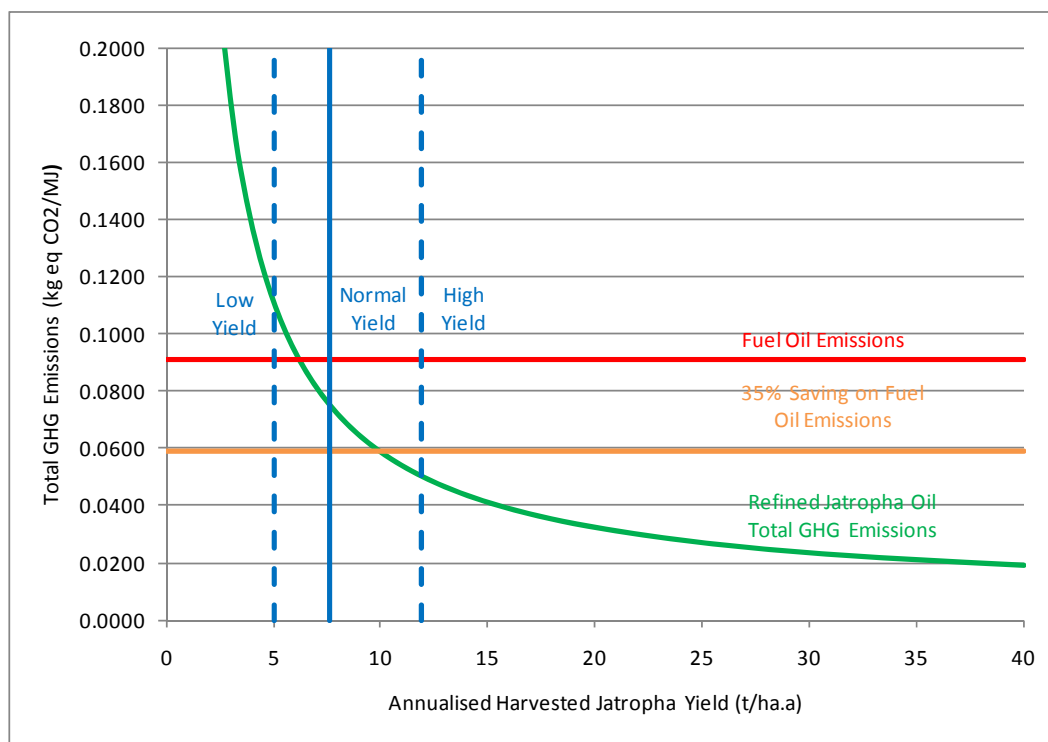


Figure B.5 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Electricity Production in Kenya Produced from Jatropha with Yield: Conversion from Scrubland, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction

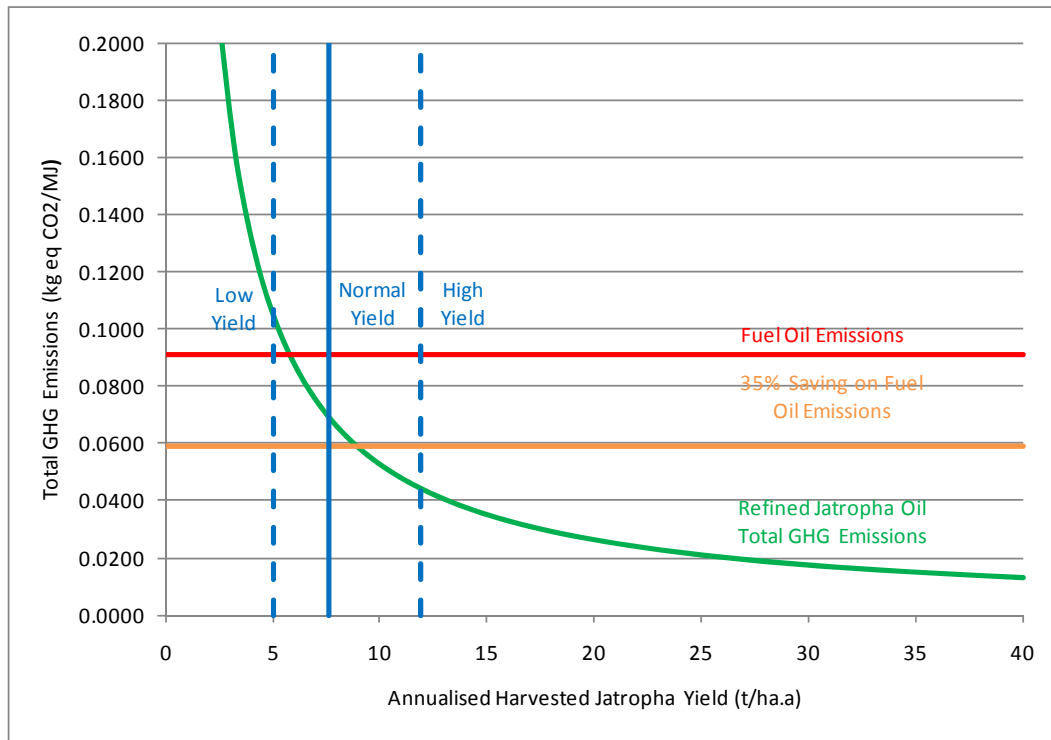


Figure B.6 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Electricity Production in Kenya Produced from Jatropha with Yield: Conversion from Scrubland, Zero Nitrogen Fertiliser Application and Biomass-fired Combined Heat and Power Unit for Oil Extraction

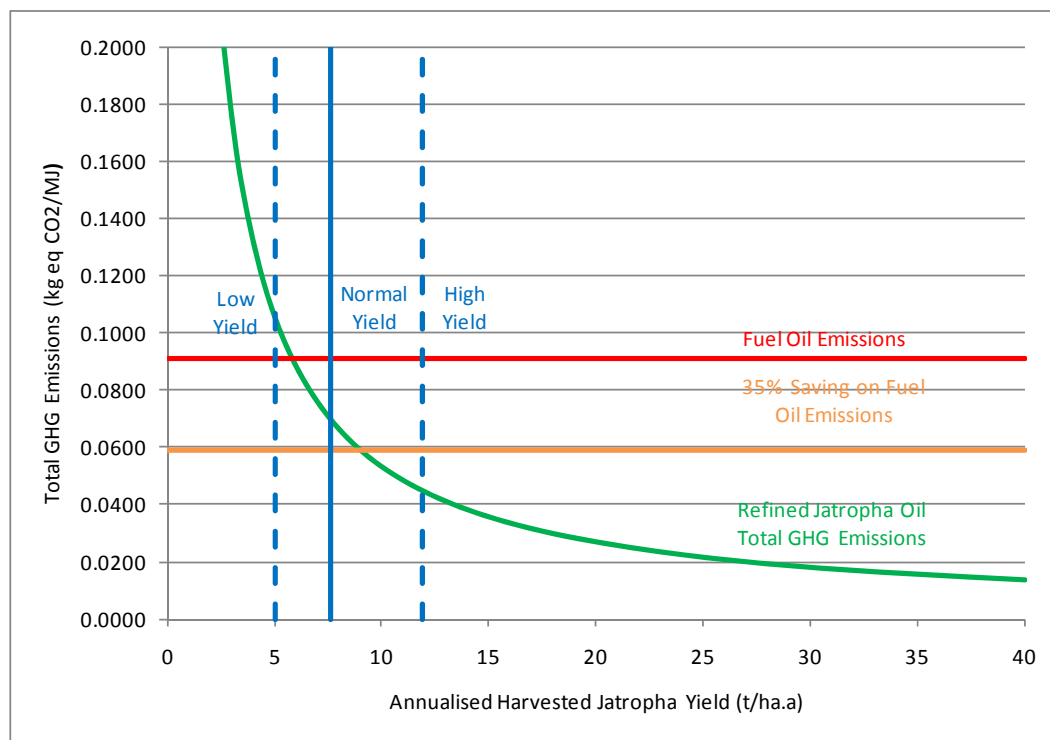


Figure B.7 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Electricity Production in Kenya Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction

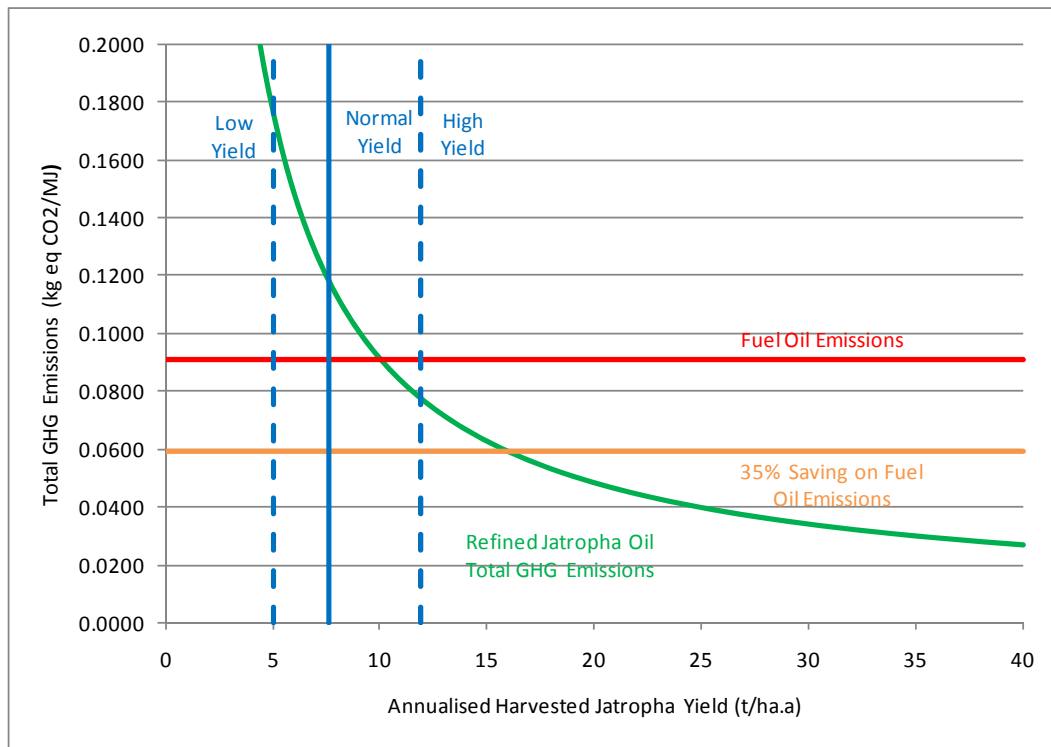


Figure B.8 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Electricity Production in Kenya Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction

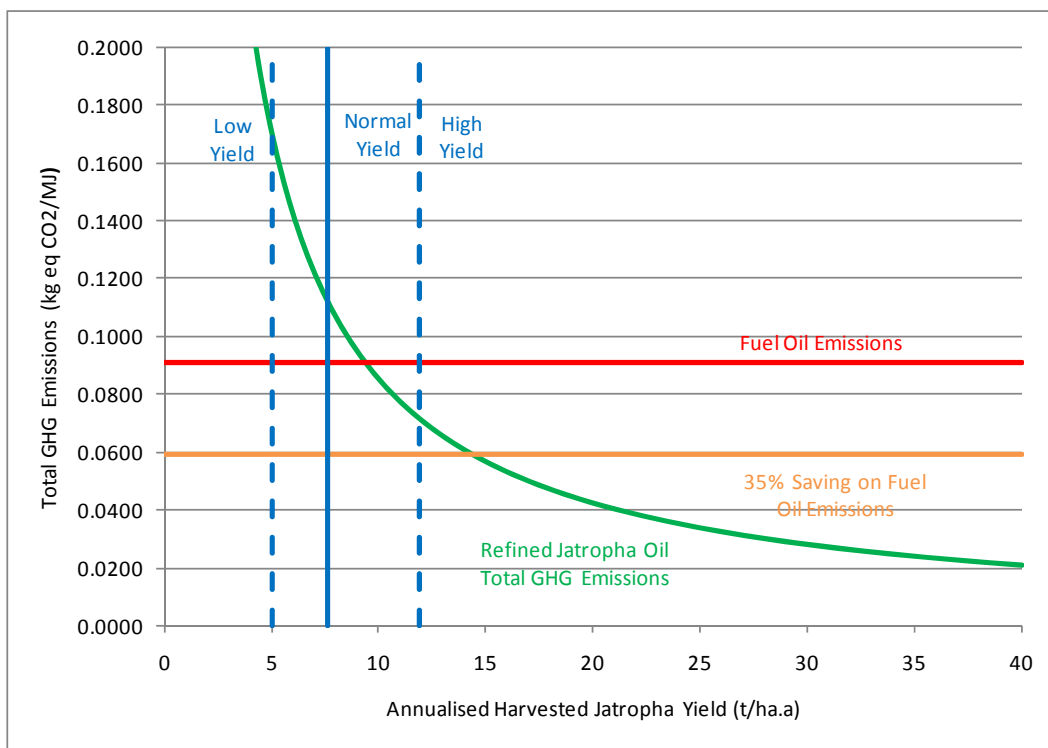


Figure B.9 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Electricity Production in Kenya Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Biomass-fired Combined Heat and Power Unit for Oil Extraction

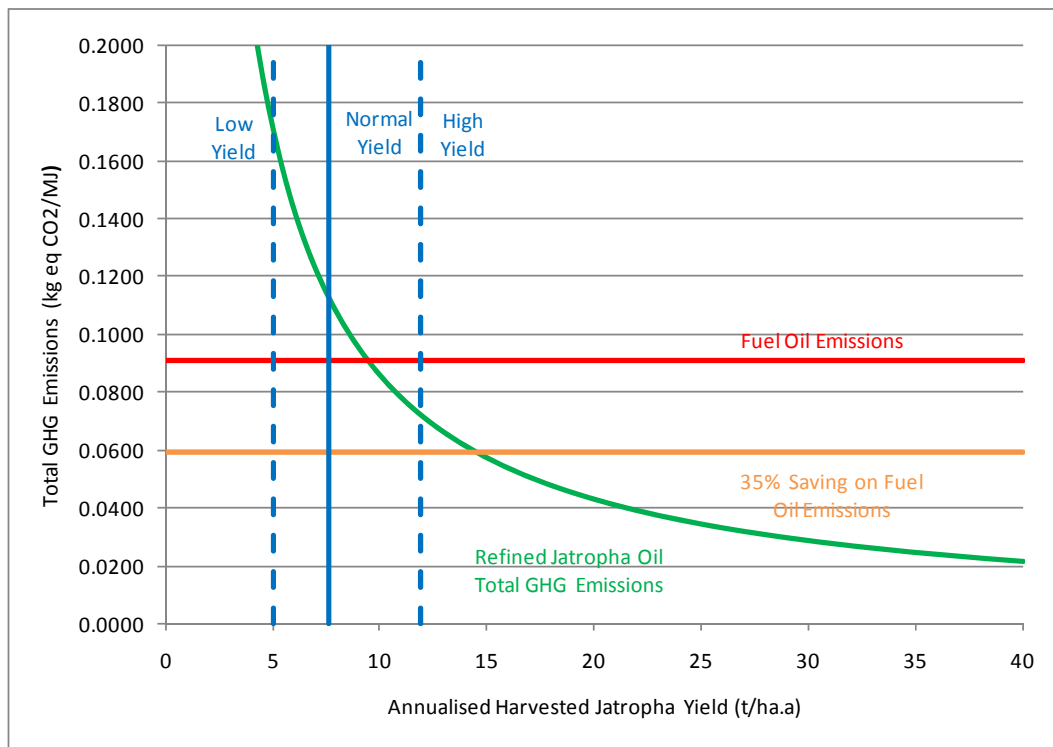


Figure B.10 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Electricity Production in Kenya Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction

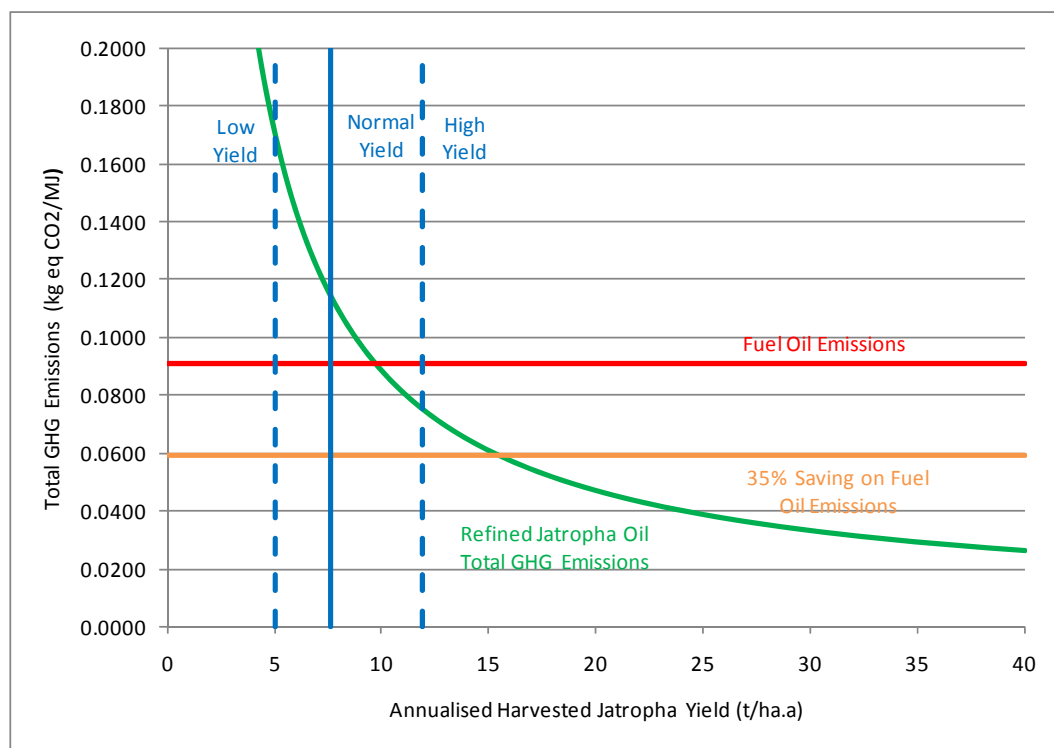


Figure B.11 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Electricity Production in Kenya Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction

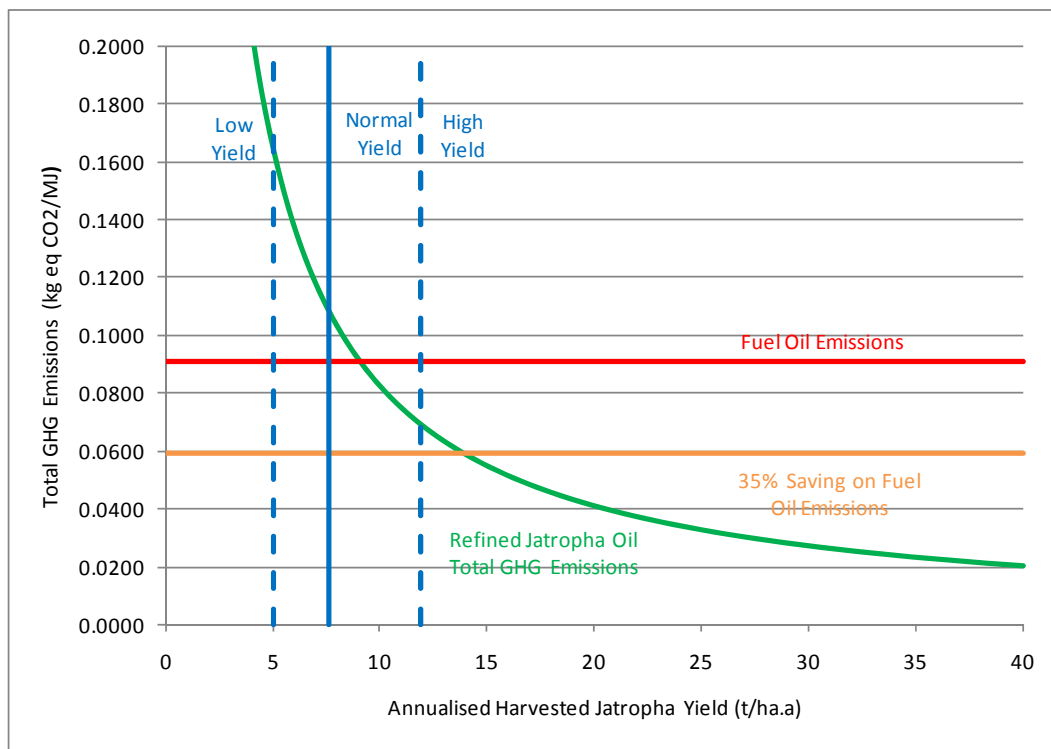


Figure B.12 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Electricity Production in Kenya Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Zero Nitrogen Fertiliser Application and Biomass-fired Combined Heat and Power Unit for Oil Extraction

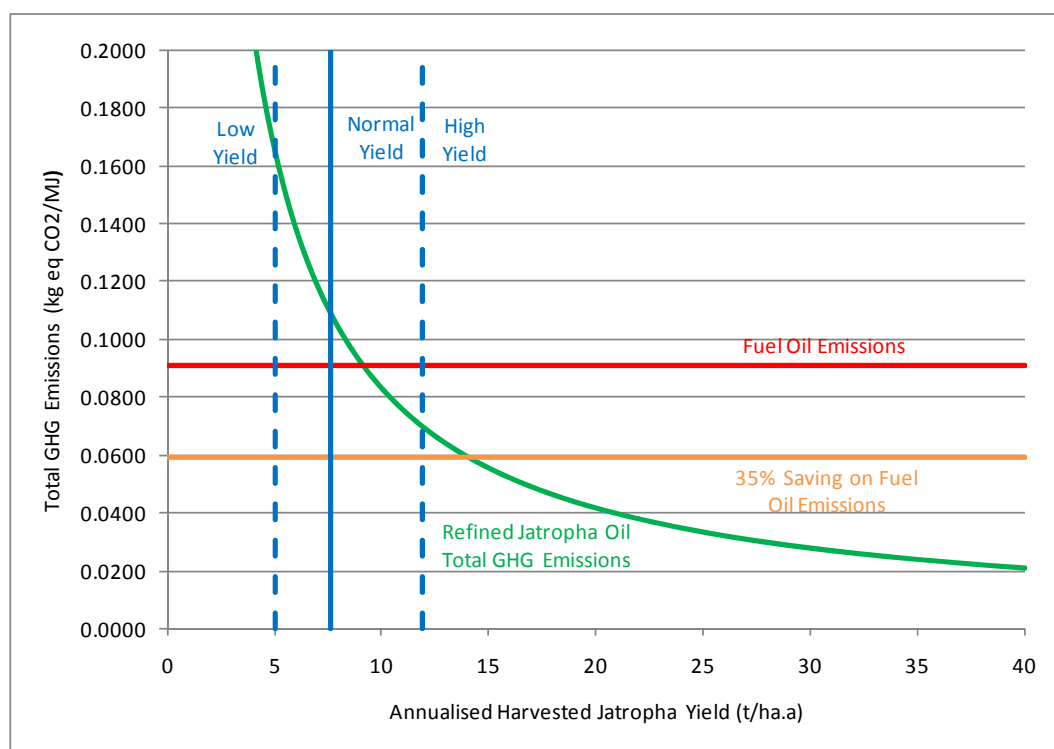


Figure B.13 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Electricity Production in Kenya Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction

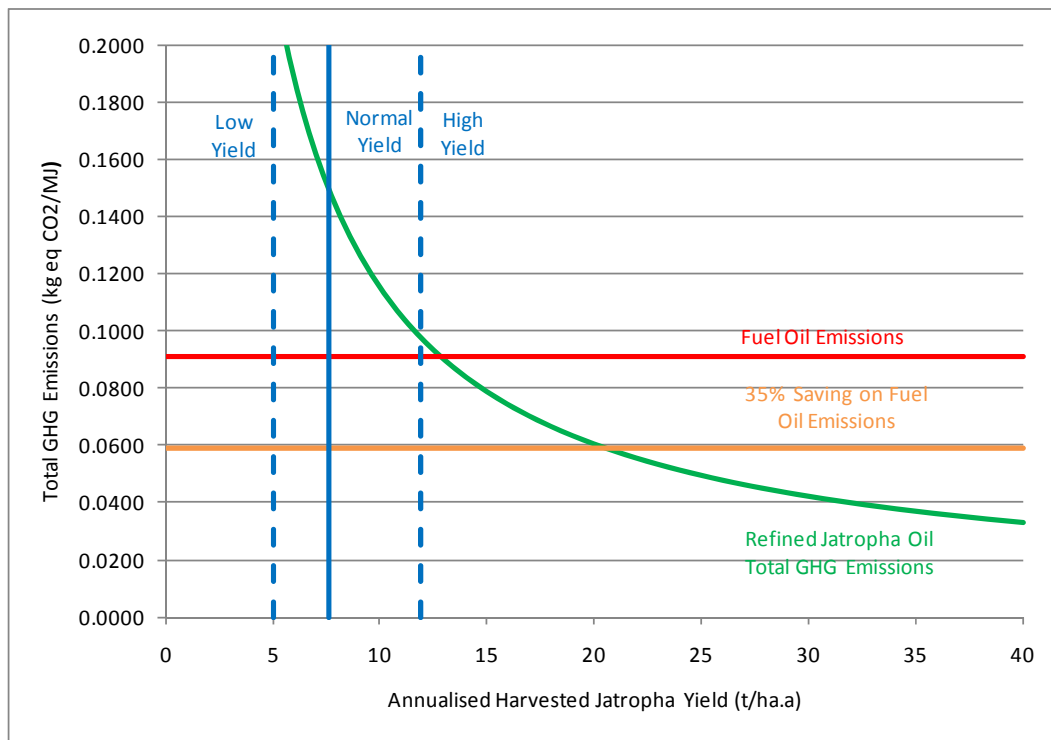


Figure B.14 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Electricity Production in Kenya Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction

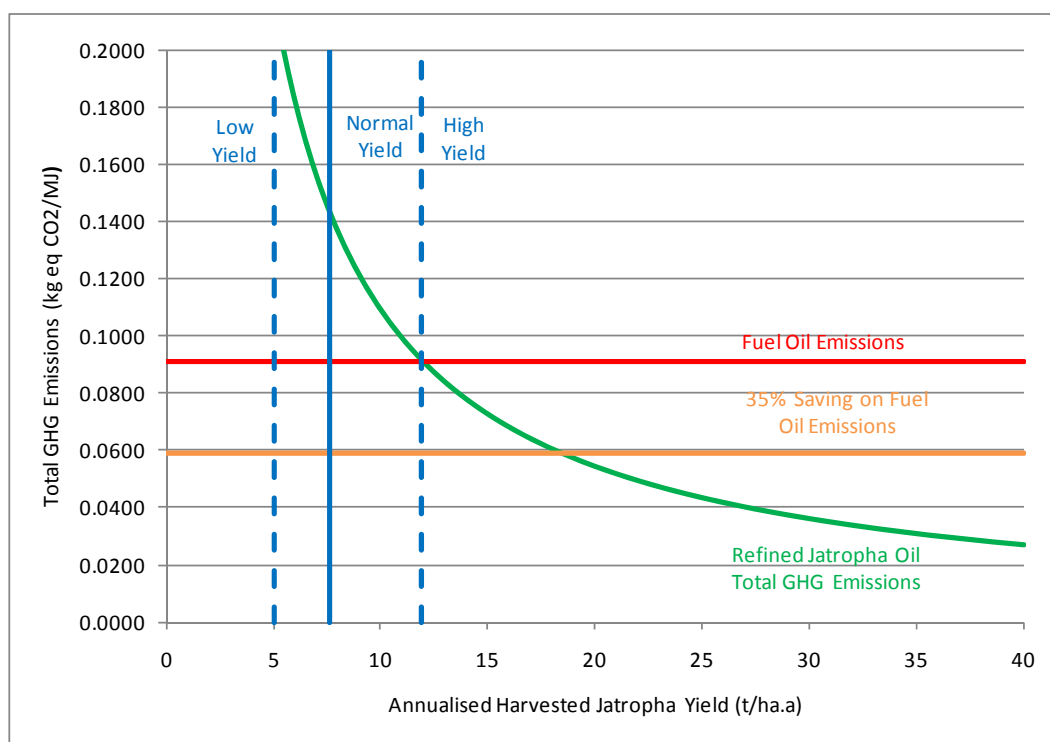


Figure B.15 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Electricity Production in Kenya Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Biomass-fired Combined Heat and Power Unit for Oil Extraction

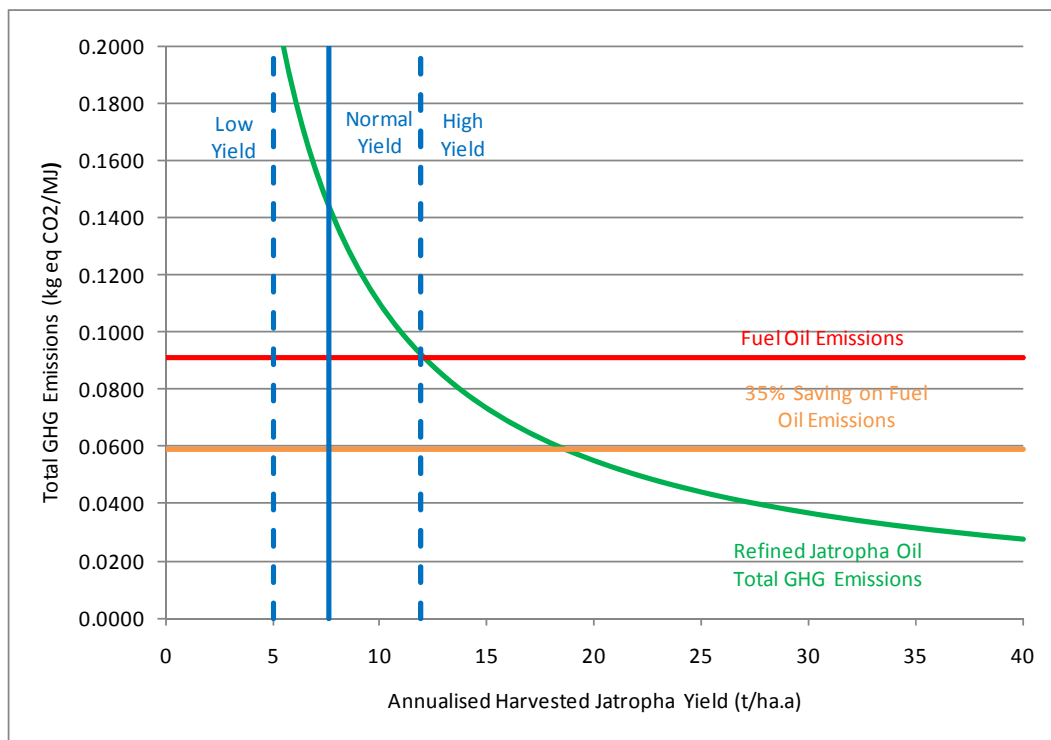


Figure B.16 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Electricity Production in Kenya Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction

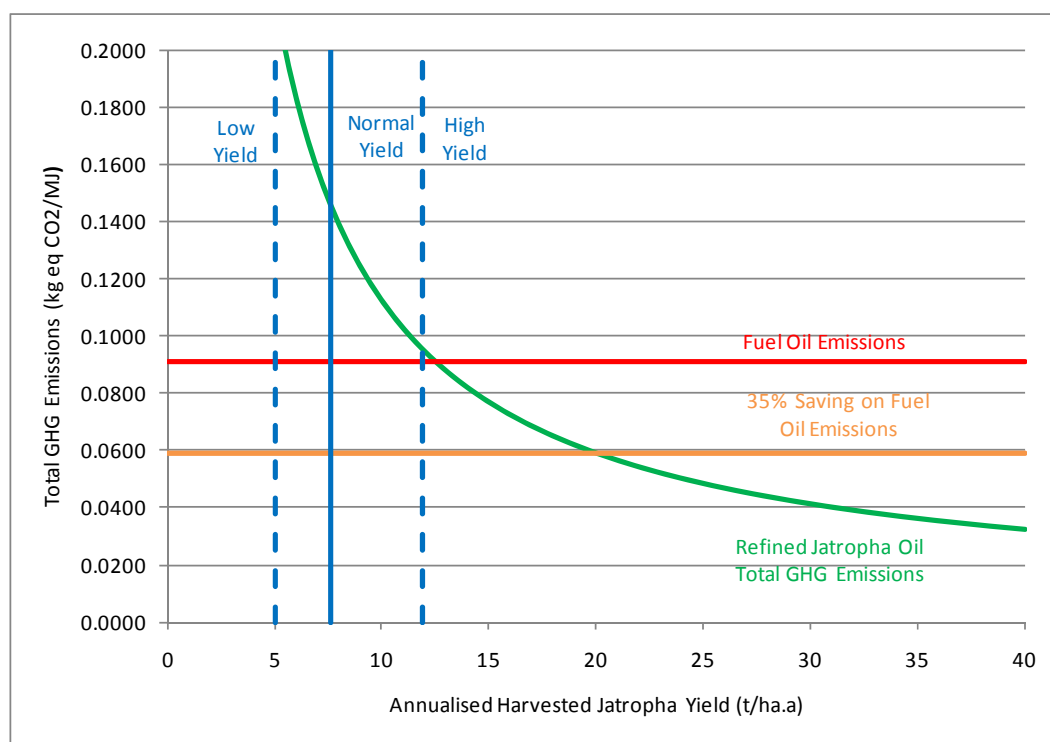


Figure B.17 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Electricity Production in Kenya Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction

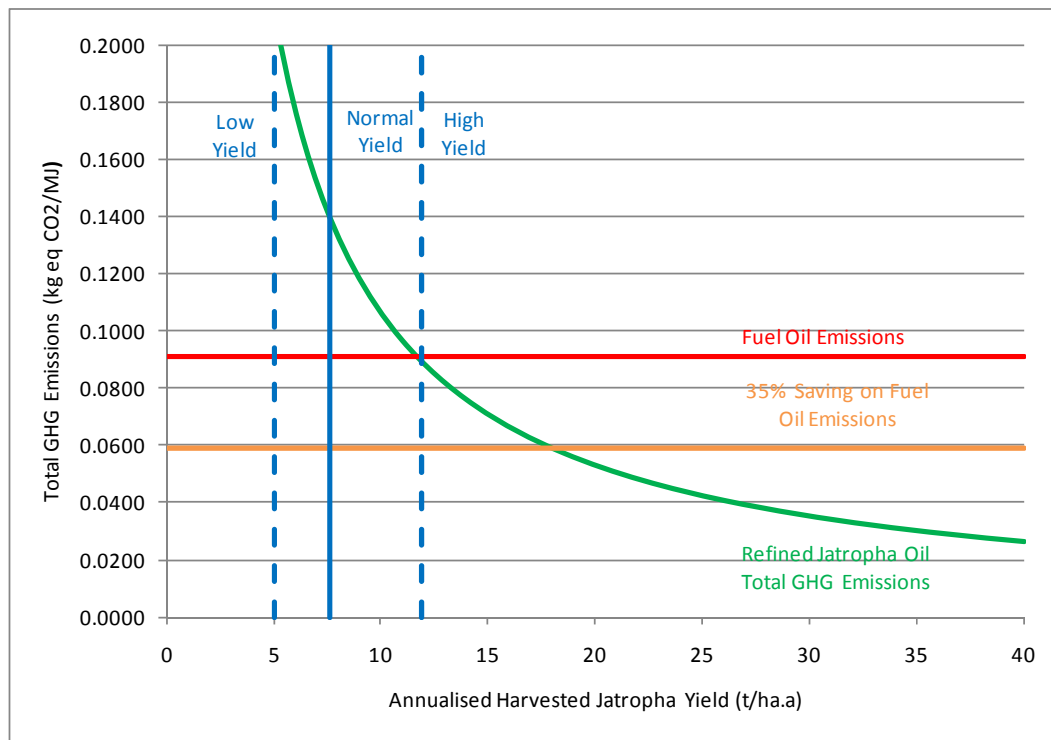
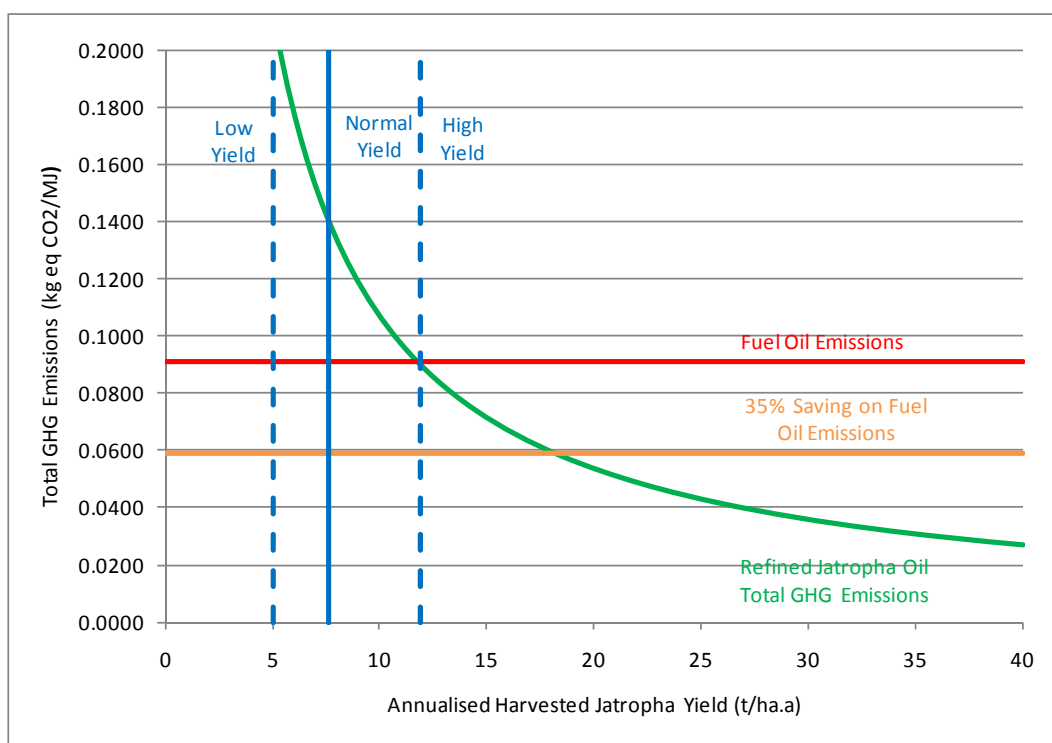


Figure B.18 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Electricity Production in Kenya Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Zero Nitrogen Fertiliser Application and Biomass-fired Combined Heat and Power Unit for Oil Extraction



APPENDIX C: Dakatcha Refined Vegetable Oil Production and Use for Cogeneration in Italy

Results generated from RSPBKenya_jat_v6.xls and recorded in RSPB Kenya Biofuels GHG dLUC 04.xls with the following assumptions:

Dried jatropha seed oil content = 35%

Jatropha conversion ratio = 3.748 t dried jatropha seed/t refined vegetable oil

Net calorific value of refined vegetable oil = 39,500 MJ/t

Figure C.1 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Scrubland, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction

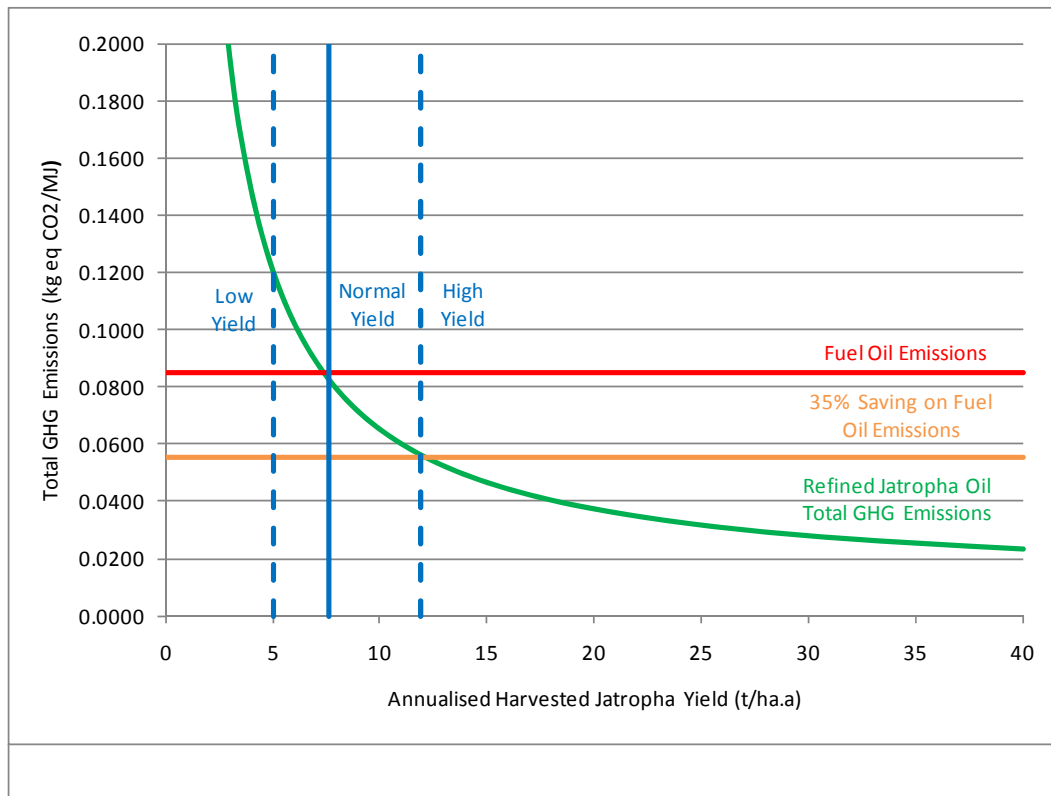


Figure C.2 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Scrubland, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction

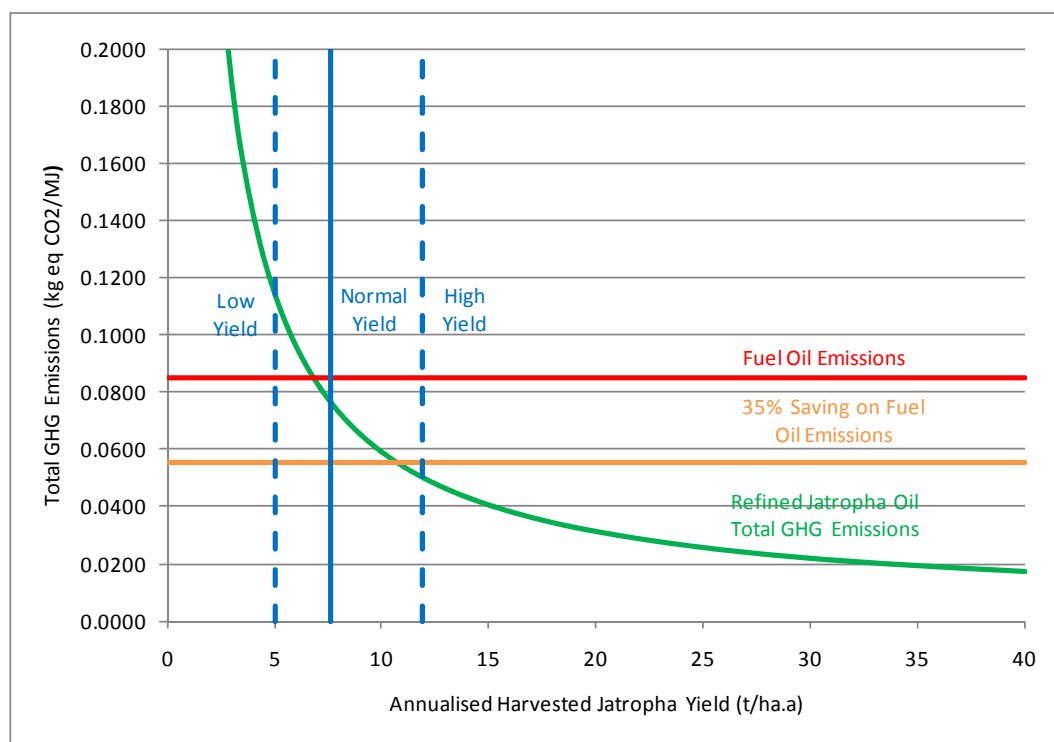


Figure C.3 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Scrubland, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Biomass-fired Combined Heat and Power Unit for Oil Extraction

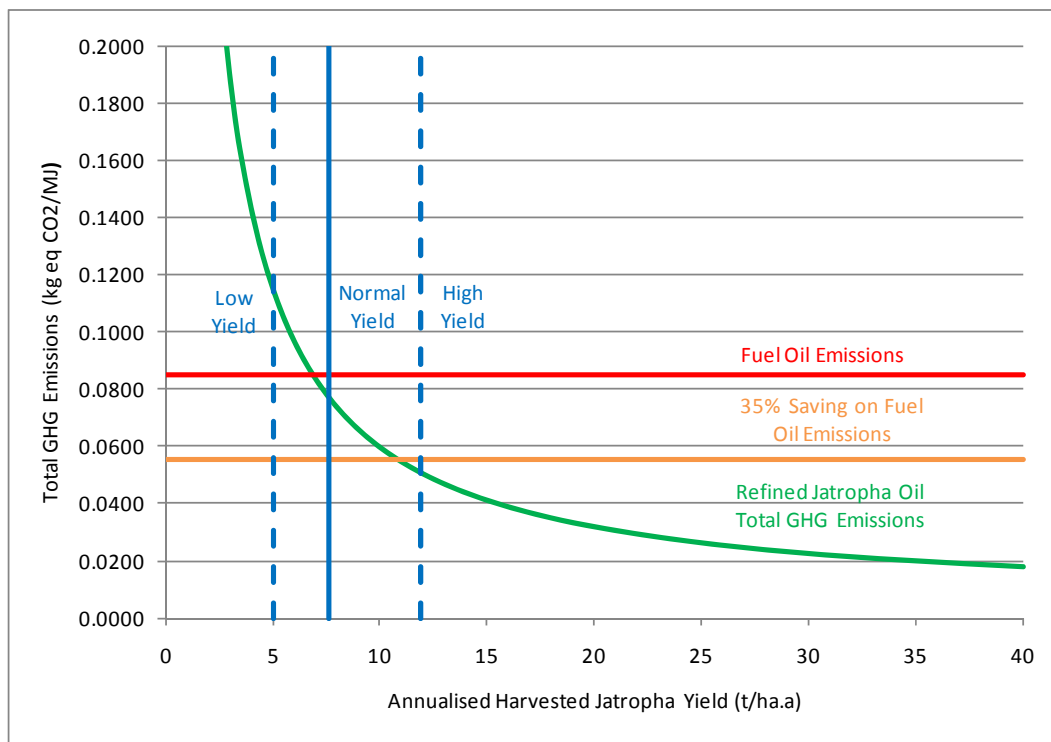


Figure C.4 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Scrubland, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction

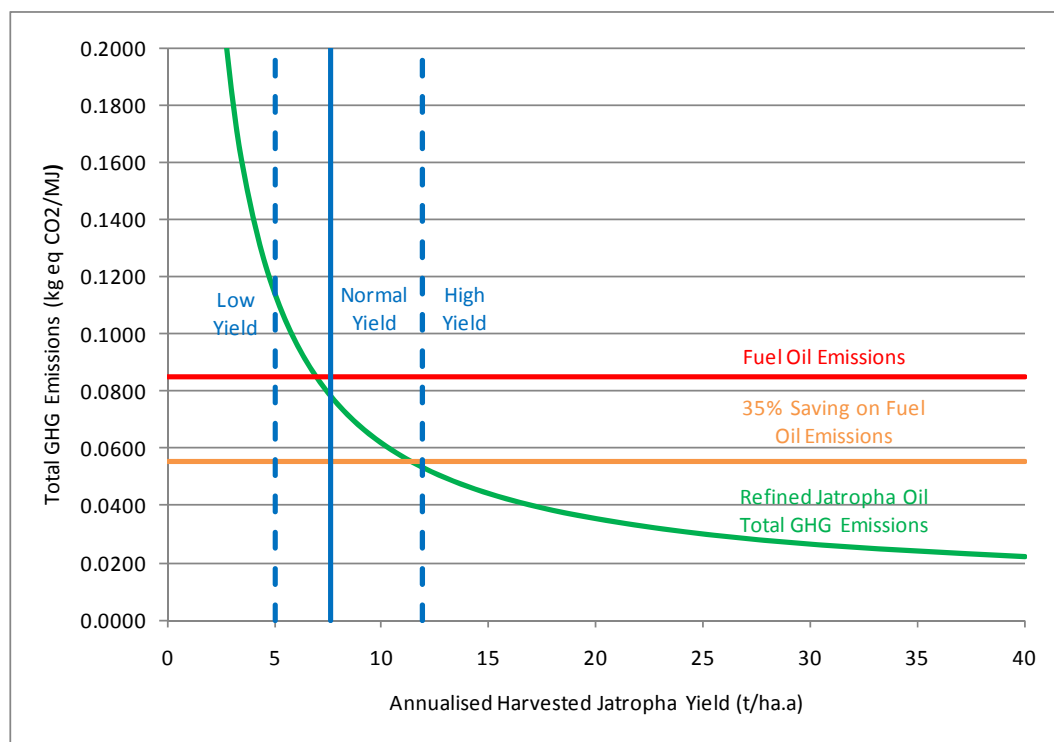


Figure C.5 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Scrubland, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction

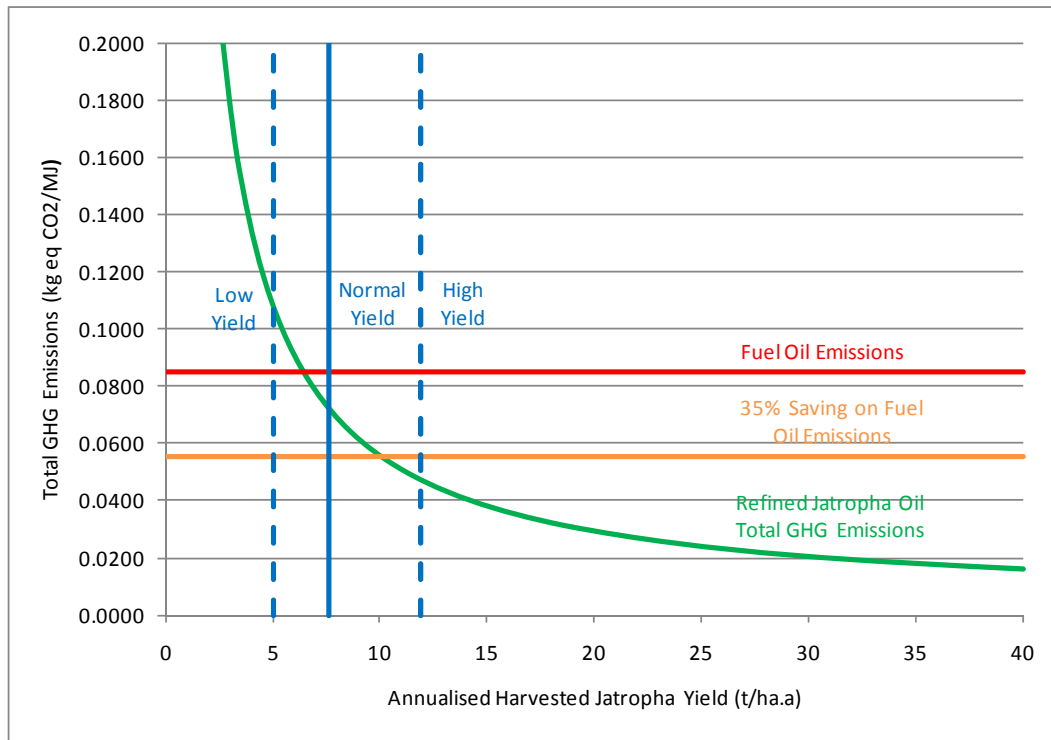


Figure C.6 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Scrubland, Zero Nitrogen Fertiliser Application and Biomass-fired Combined Heat and Power Unit for Oil Extraction

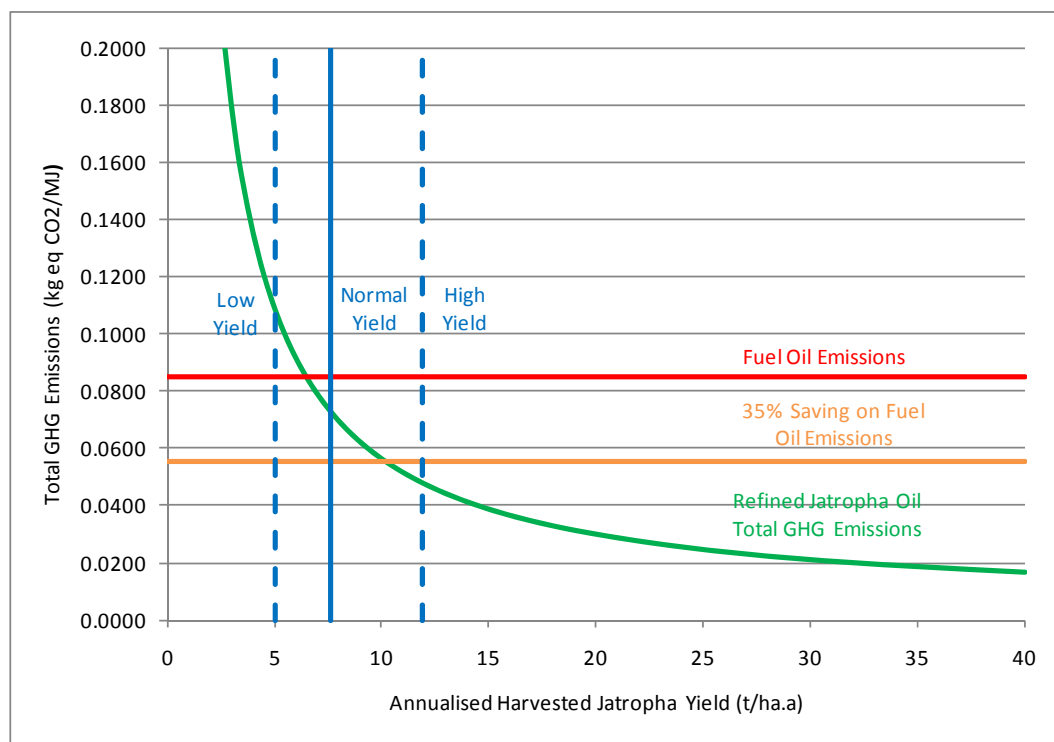


Figure C.7 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction

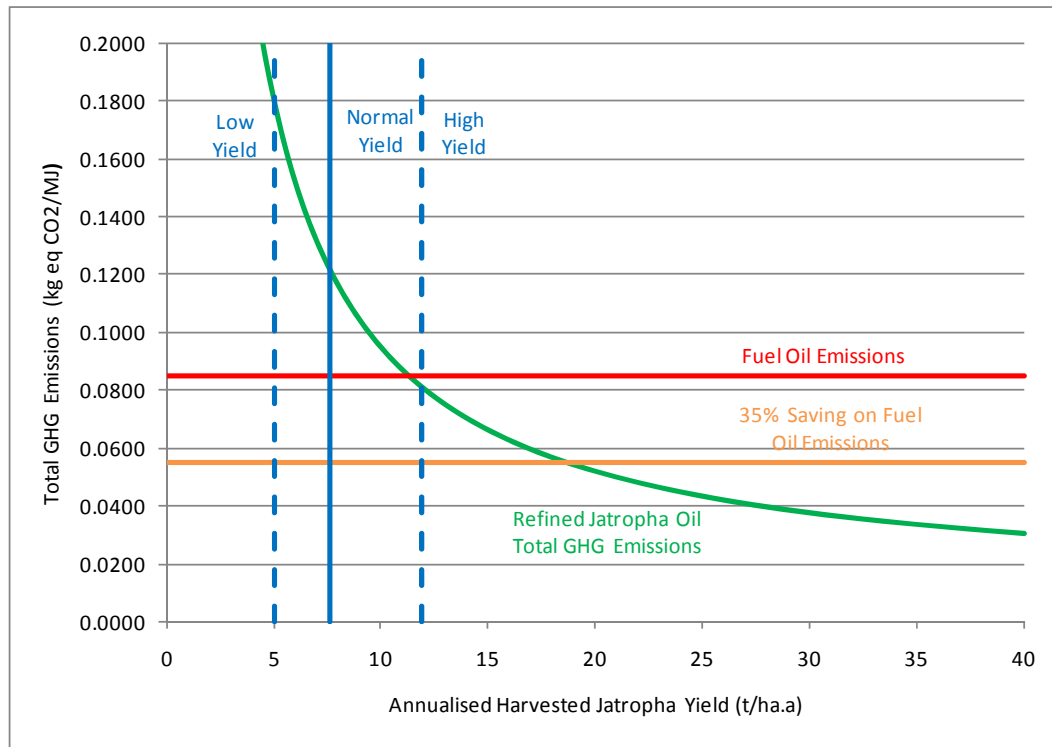


Figure C.8 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction

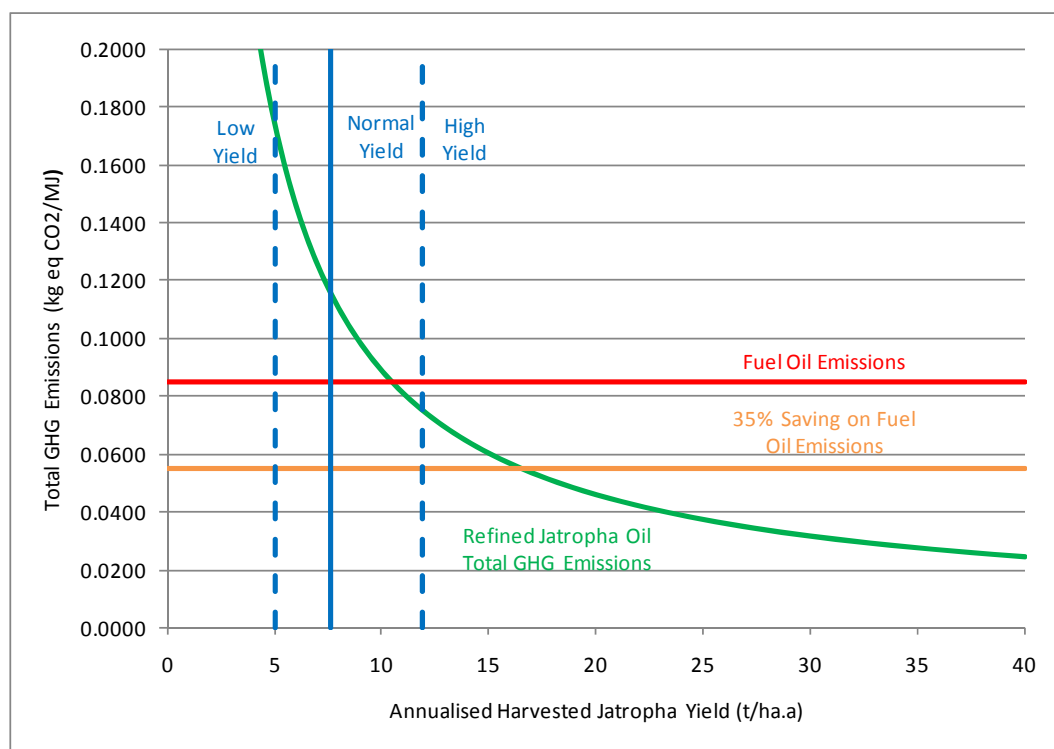


Figure C.9 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Biomass-fired Combined Heat and Power Unit for Oil Extraction

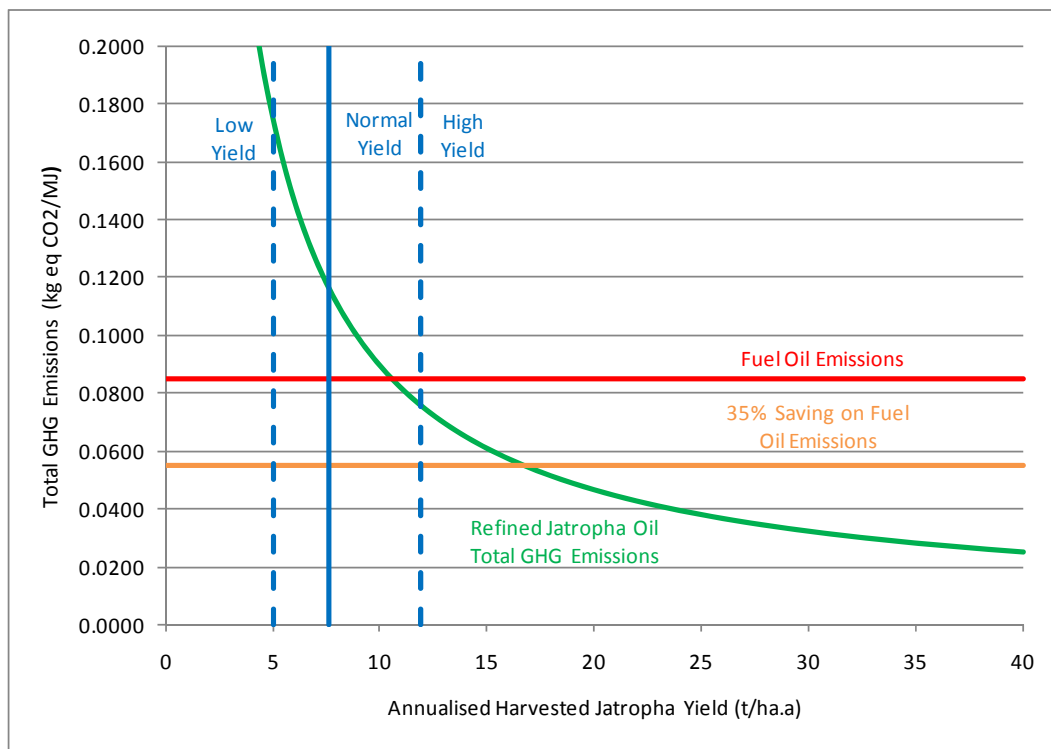


Figure C.10 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction

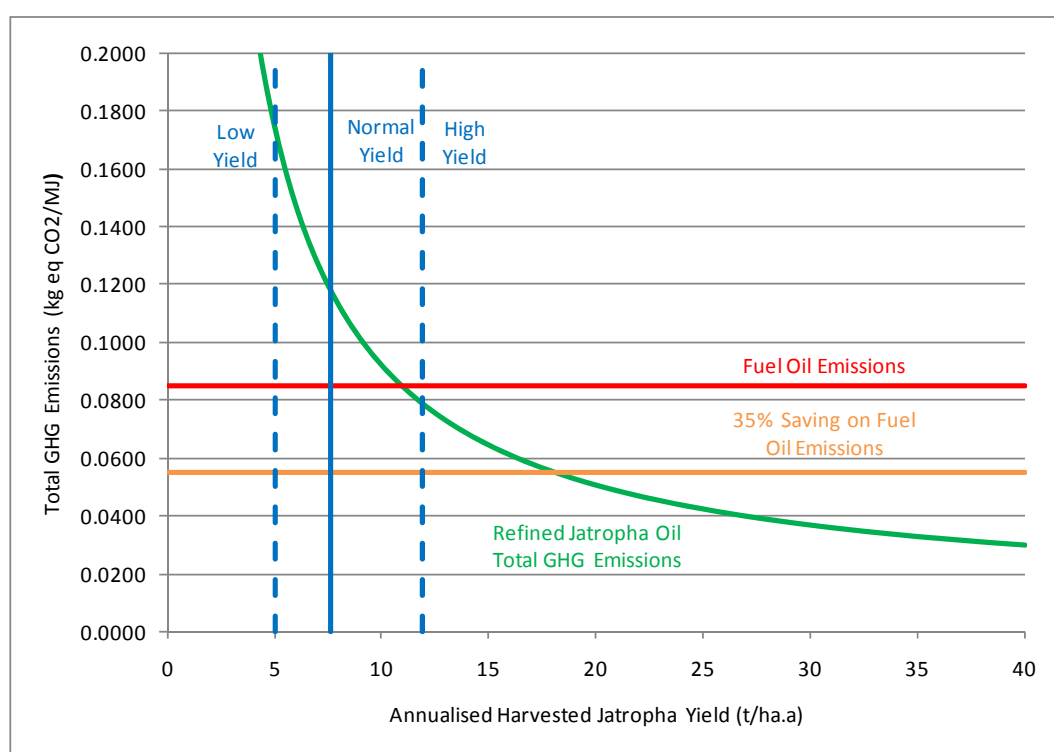


Figure C.11 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction

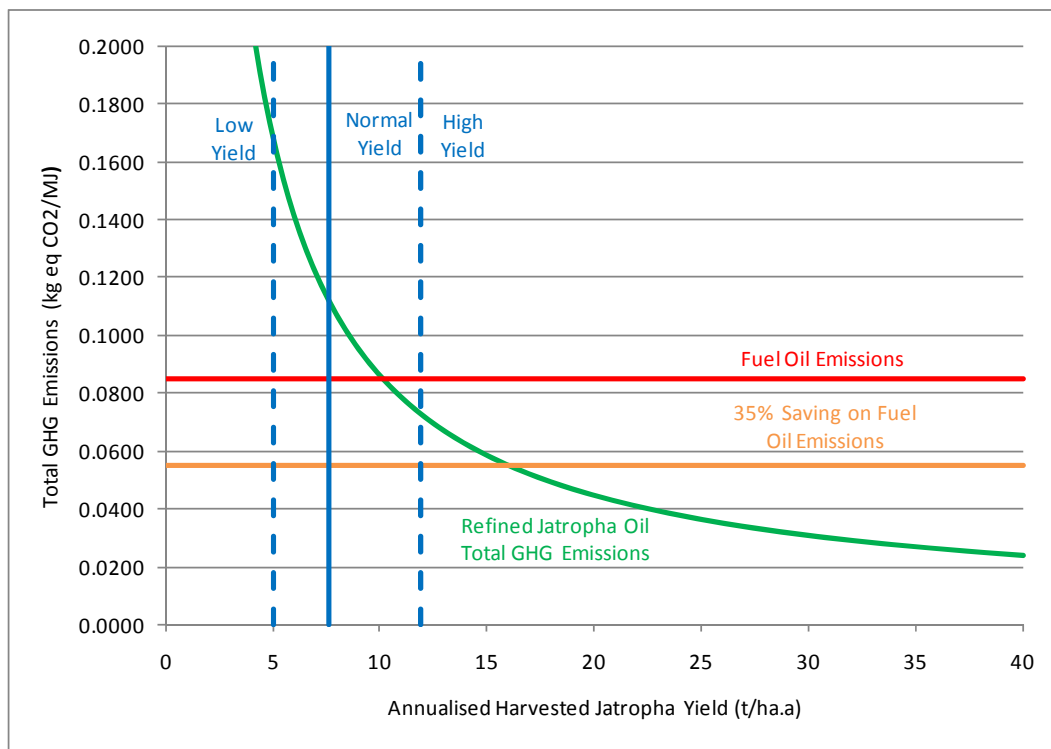


Figure C.12 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Zero Nitrogen Fertiliser Application and Biomass-fired Combined Heat and Power Unit for Oil Extraction

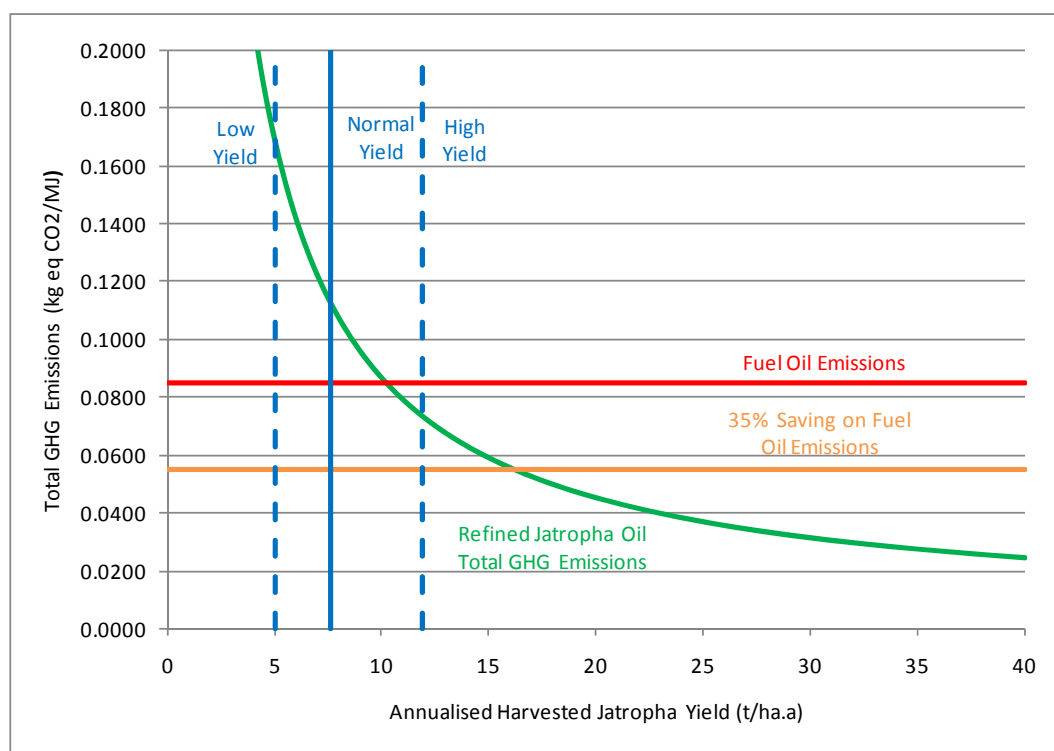


Figure C.13 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction

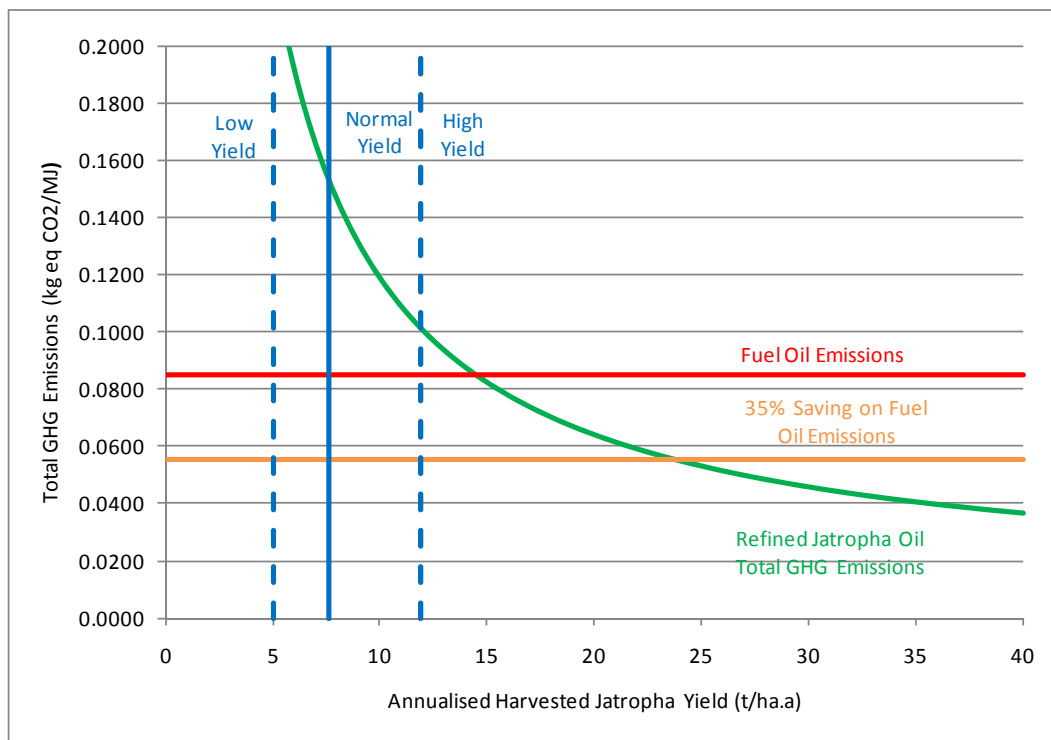


Figure C.14 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction

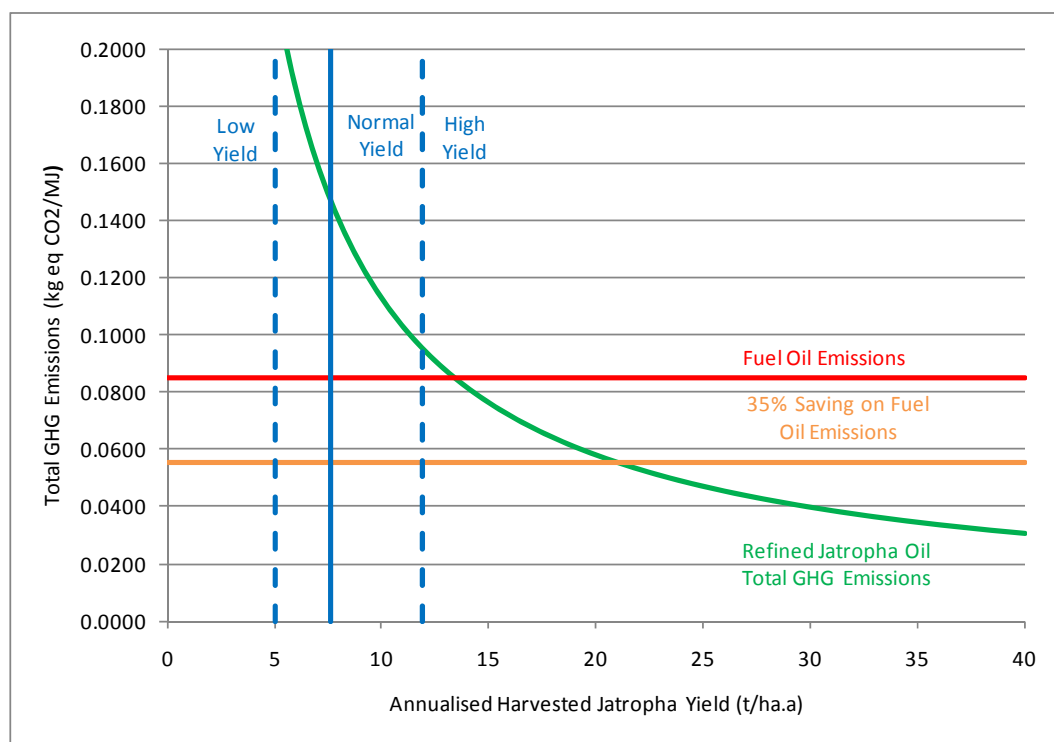


Figure C.15 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Biomass-fired Combined Heat and Power Unit for Oil Extraction

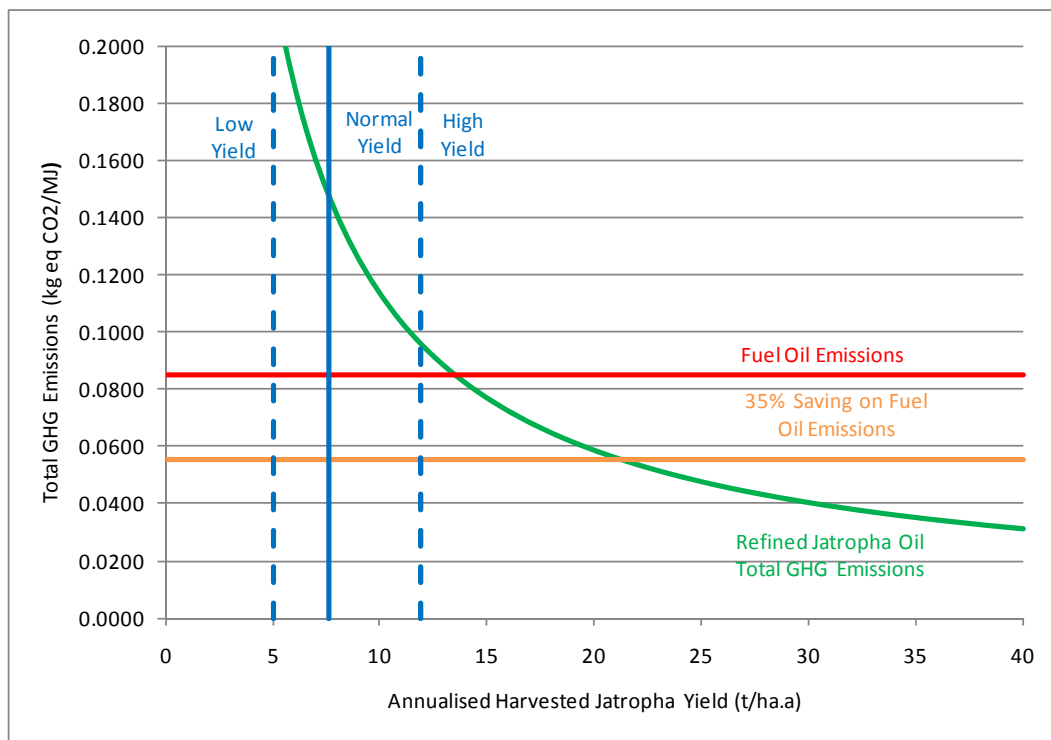


Figure C.16 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction

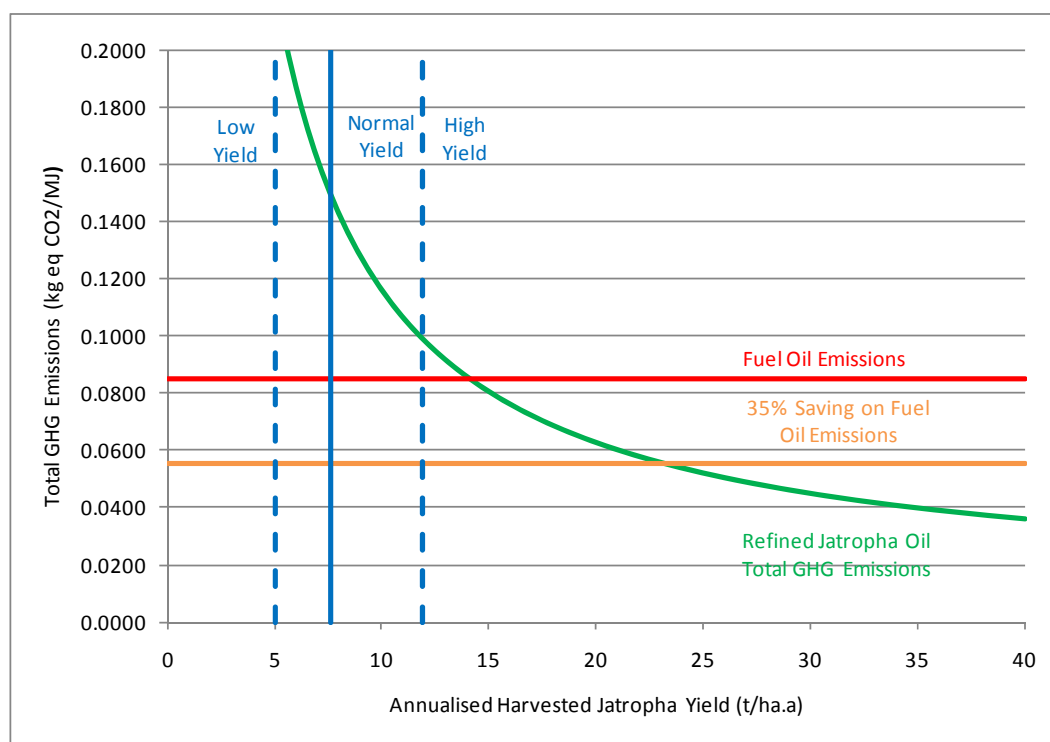


Figure C.17 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction

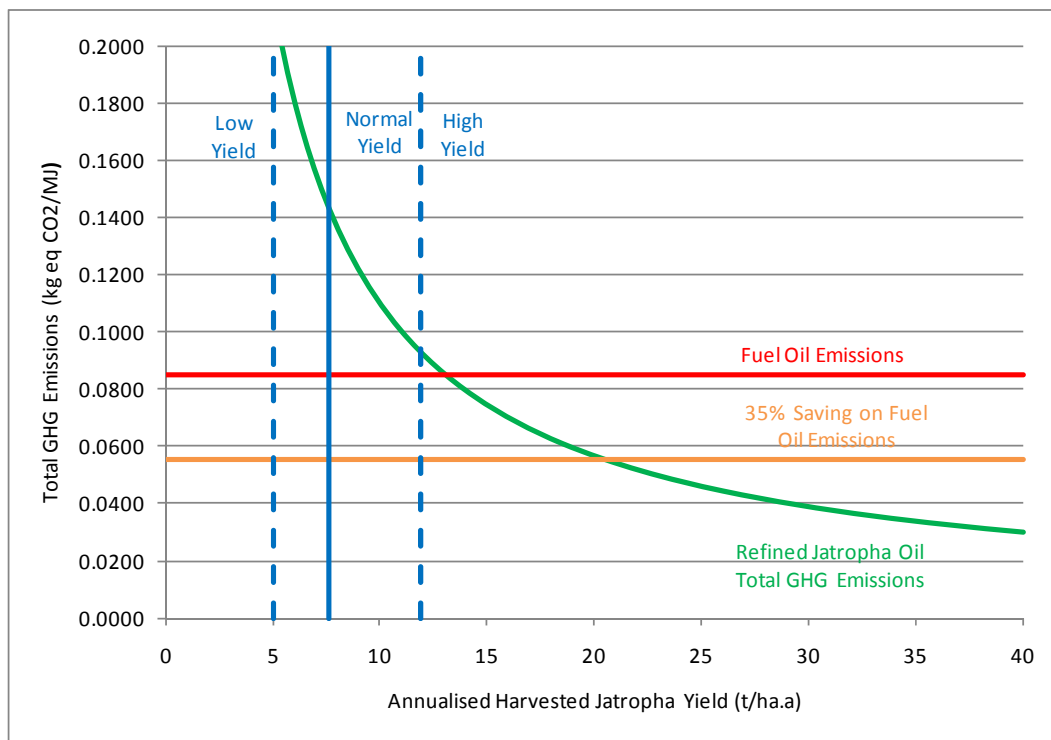
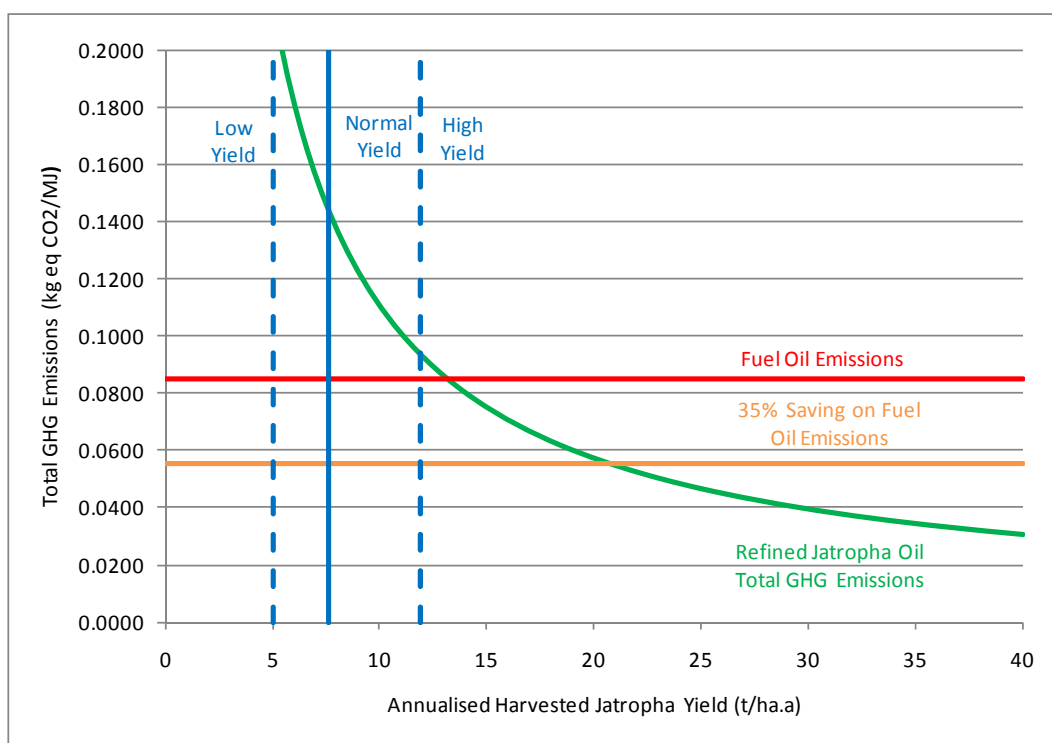


Figure C.18 Variation of Total Greenhouse Gas Emissions for Refined Vegetable Oil for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Zero Nitrogen Fertiliser Application and Biomass-fired Combined Heat and Power Unit for Oil Extraction



APPENDIX D: Dakatcha Biodiesel Production and Use for Transport in Kenya

Results generated from RSPBKenya_jat_v6.xls and recorded in RSPB Kenya Biofuels GHG dLUC 04.xls with the following assumptions:

Dried jatropha seed oil content = 35%

Jatropha conversion ratio = 3.945 t dried jatropha seed/t biodiesel

Net calorific value of biodiesel = 37,200 MJ/t

Figure D.1 Variation of Total Greenhouse Gas Emissions for Biodiesel for Transport in Kenya Produced from Jatropha with Yield: Conversion from Scrubland, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction and Transesterification Plant

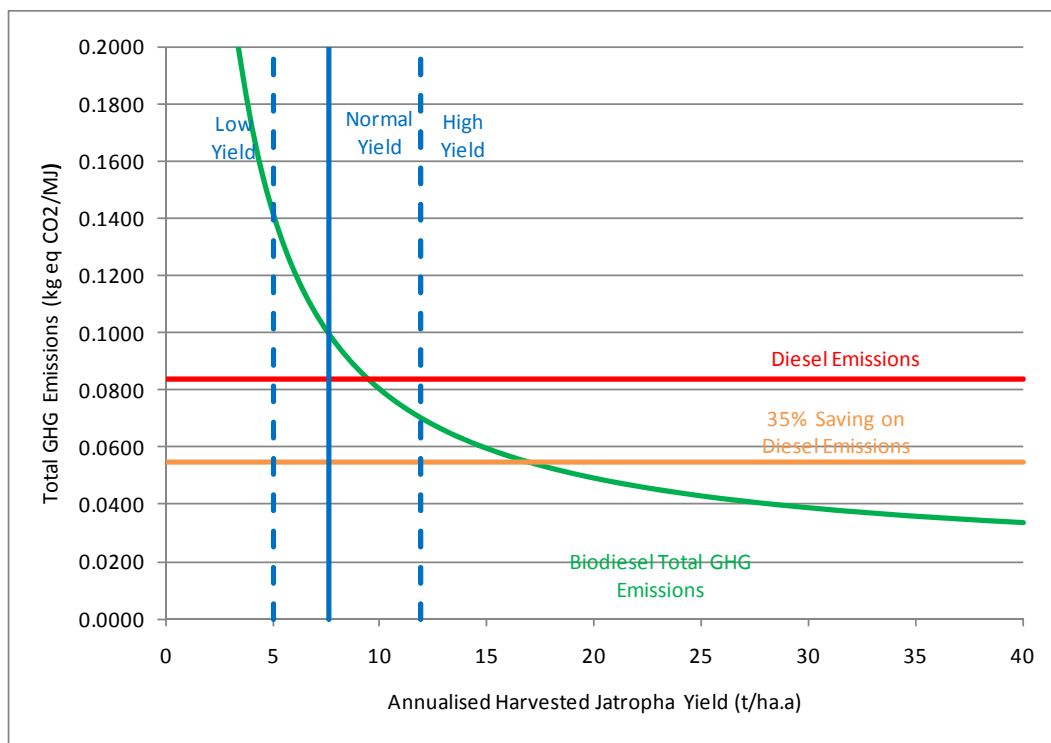


Figure D.2 Variation of Total Greenhouse Gas Emissions for Biodiesel for Transport in Kenya Produced from Jatropha with Yield: Conversion from Scrubland, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

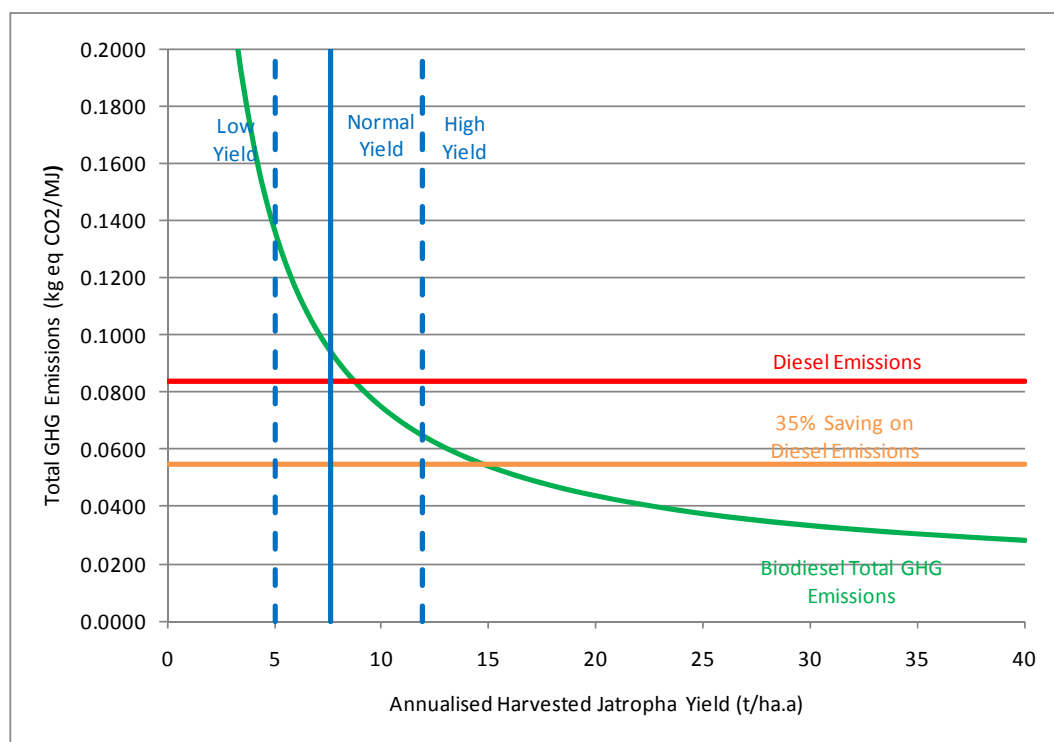


Figure D.3 Variation of Total Greenhouse Gas Emissions for Biodiesel for Transport in Kenya Produced from Jatropha with Yield: Conversion from Scrubland, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Biomass-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

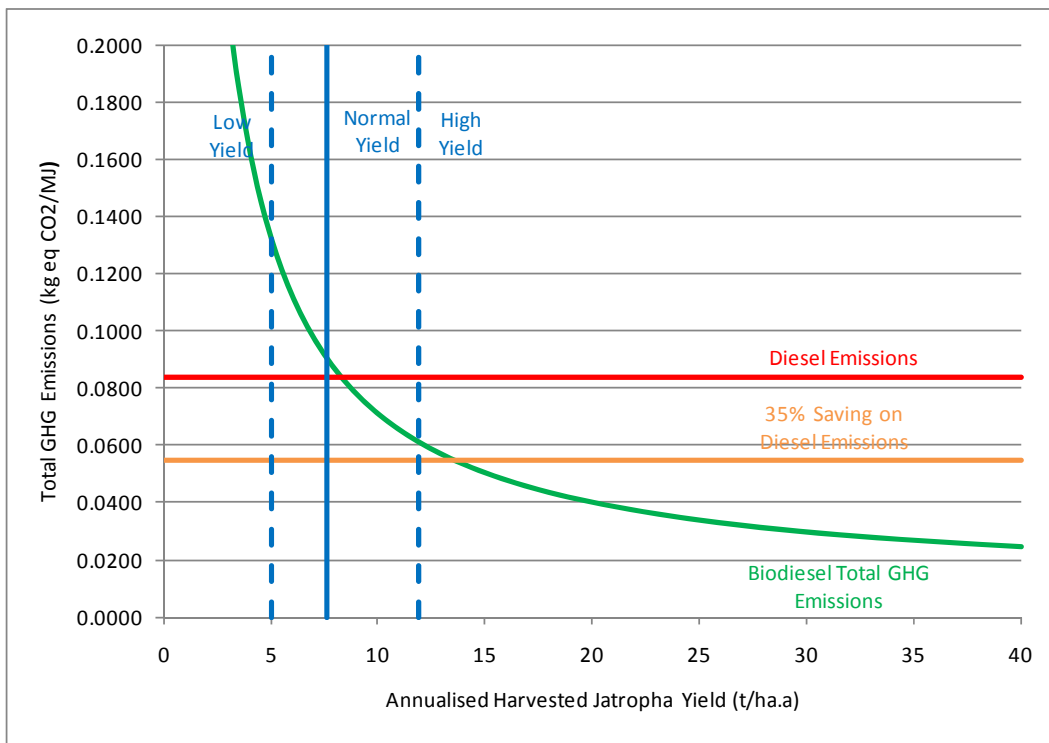


Figure D.4 Variation of Total Greenhouse Gas Emissions for Biodiesel for Transport in Kenya Produced from Jatropha with Yield: Conversion from Scrubland, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction and Transesterification Plant

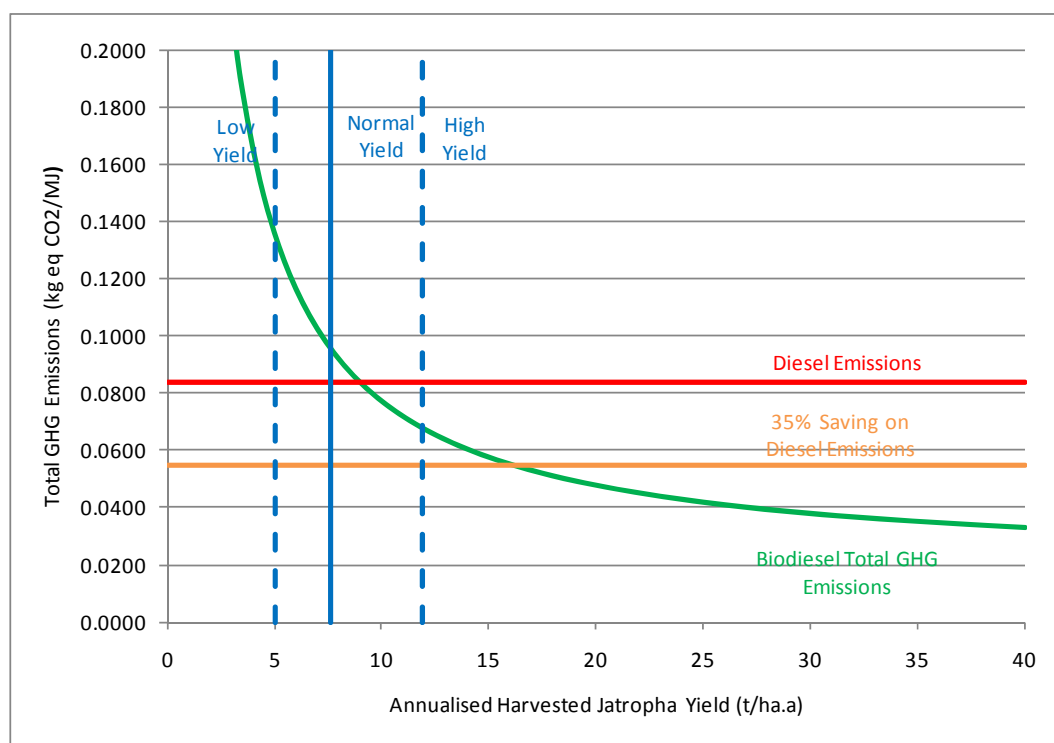


Figure D.5 Variation of Total Greenhouse Gas Emissions for Biodiesel for Transport in Kenya Produced from Jatropha with Yield: Conversion from Scrubland, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

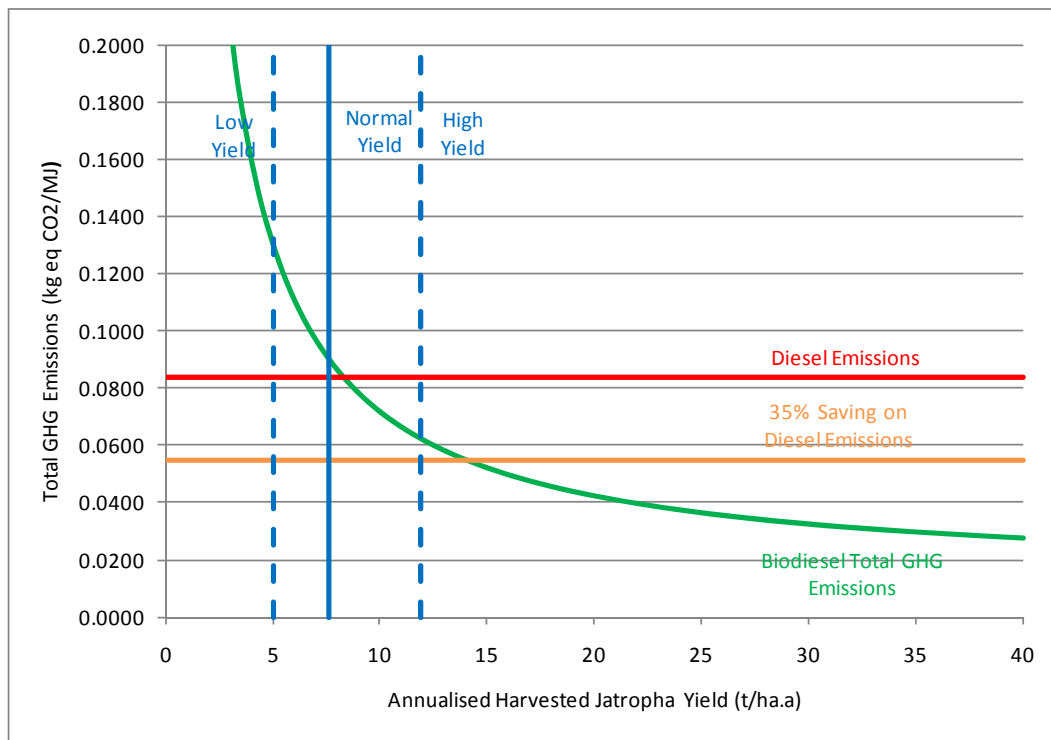


Figure D.6 Variation of Total Greenhouse Gas Emissions for Biodiesel for Transport in Kenya Produced from Jatropha with Yield: Conversion from Scrubland, Zero Nitrogen Fertiliser Application and Biomass-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

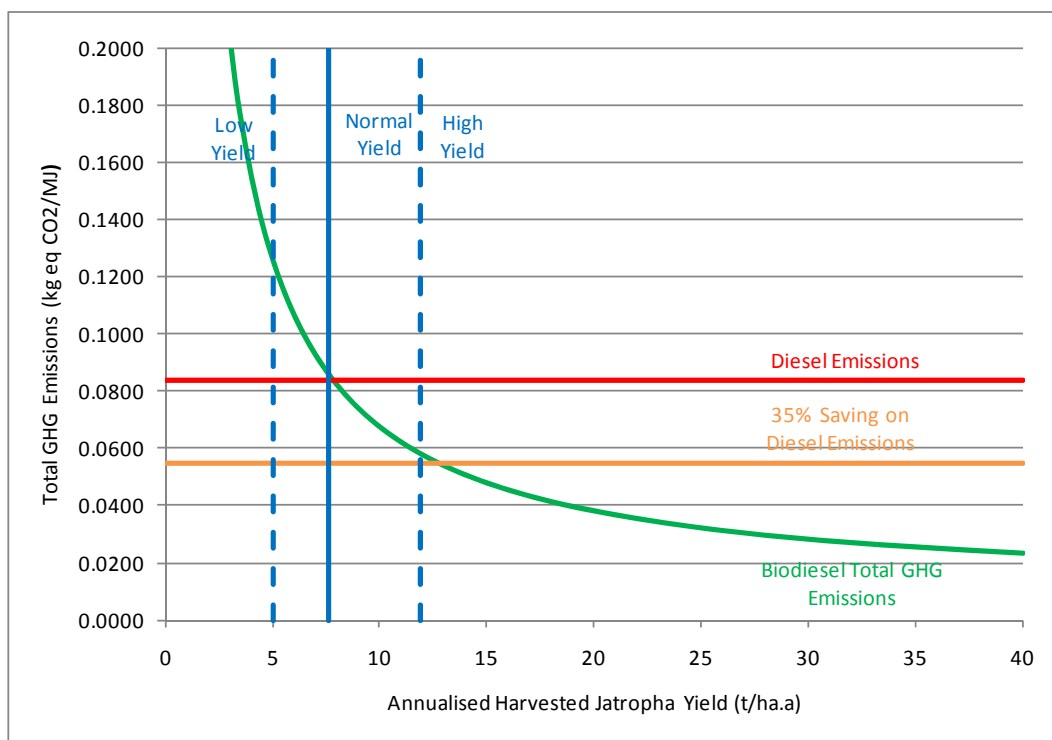


Figure D.7 Variation of Total Greenhouse Gas Emissions for Biodiesel for Transport in Kenya Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction and Transesterification Plant

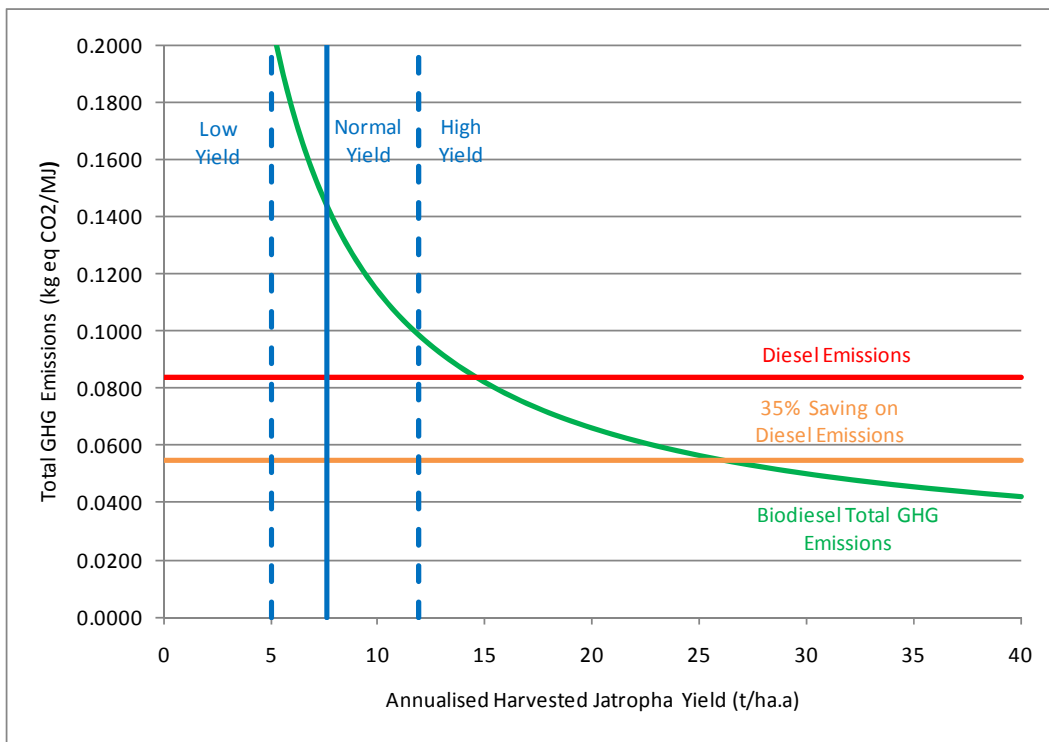


Figure D.8 Variation of Total Greenhouse Gas Emissions for Biodiesel for Transport in Kenya Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

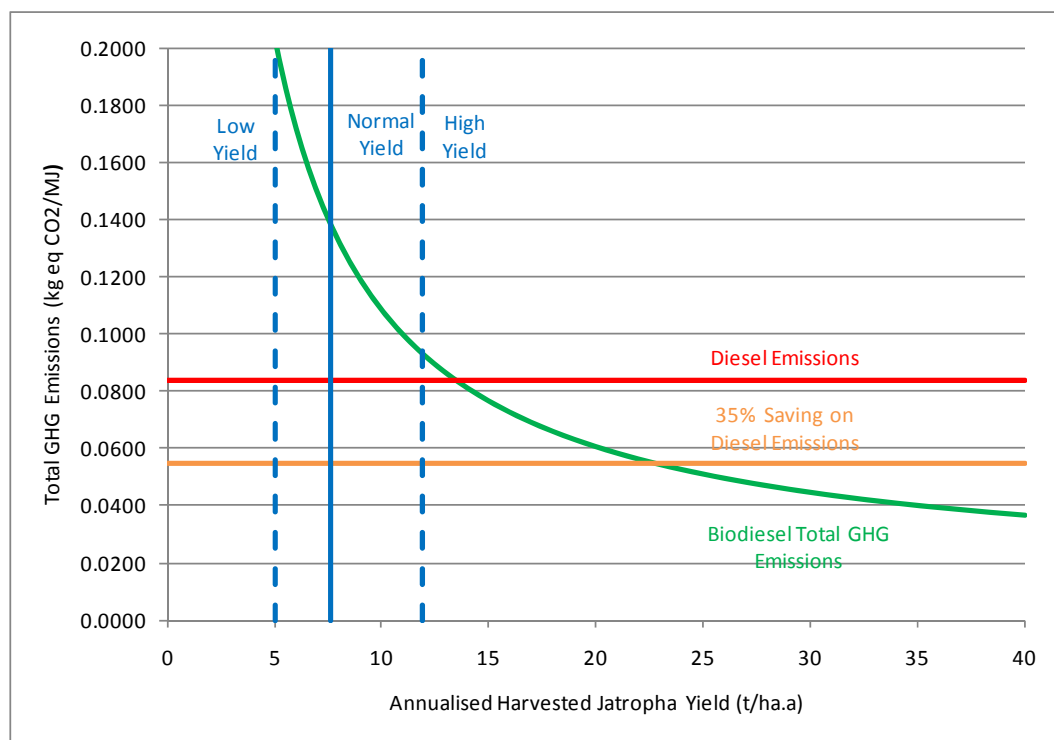


Figure D.9 Variation of Total Greenhouse Gas Emissions for Biodiesel for Transport in Kenya Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Biomass-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

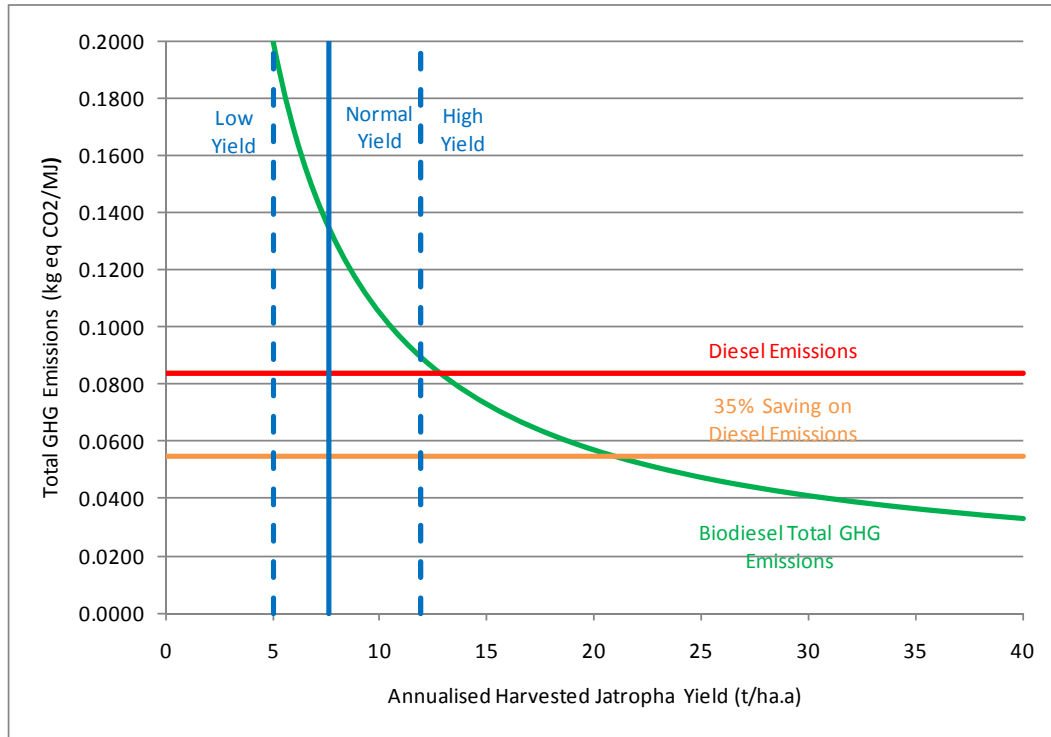


Figure D.10 Variation of Total Greenhouse Gas Emissions for Biodiesel for Transport in Kenya Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction and Transesterification Plant

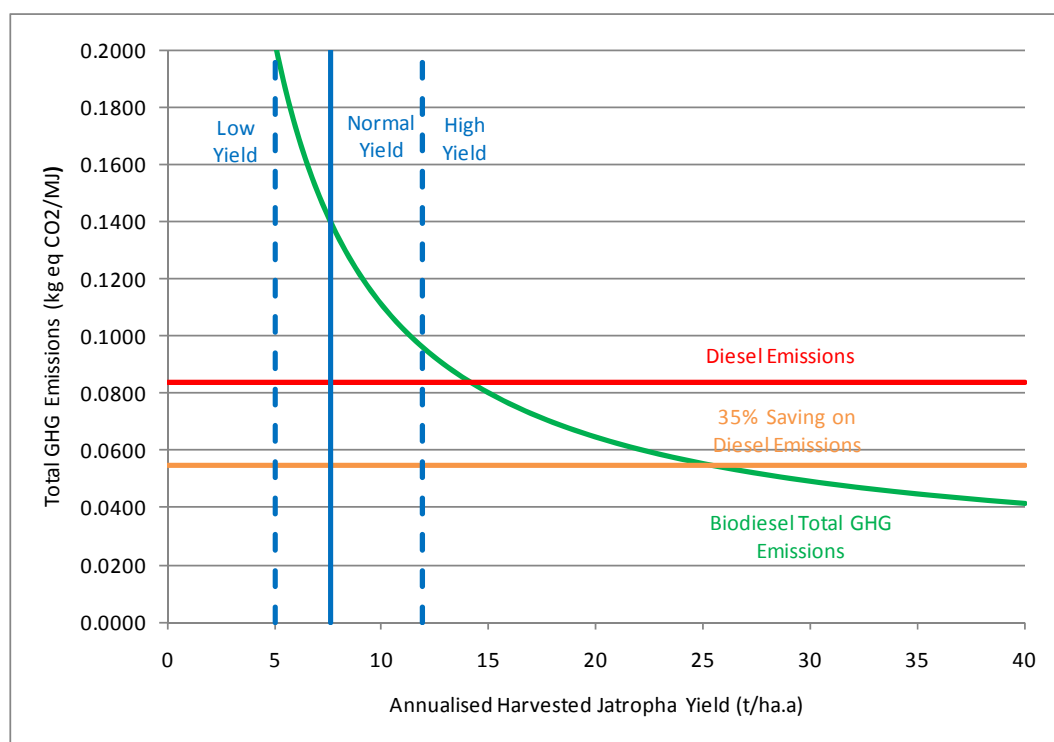


Figure D.11 Variation of Total Greenhouse Gas Emissions for Biodiesel for Transport in Kenya Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

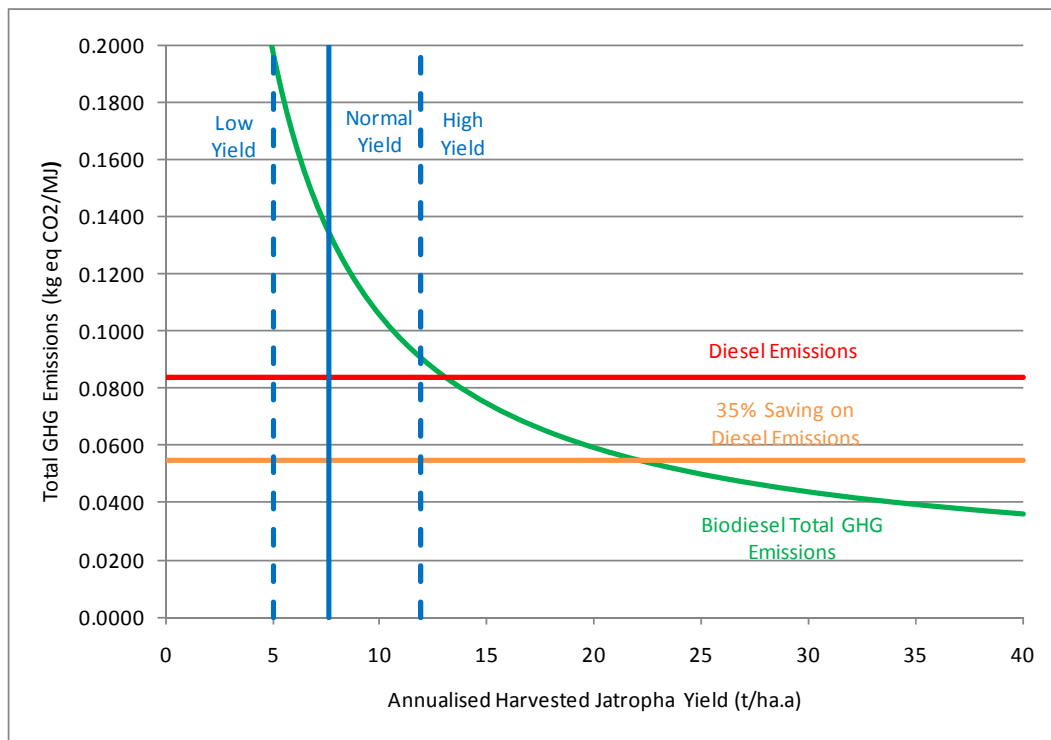


Figure D.12 Variation of Total Greenhouse Gas Emissions for Biodiesel for Transport in Kenya Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Zero Nitrogen Fertiliser Application and Biomass-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

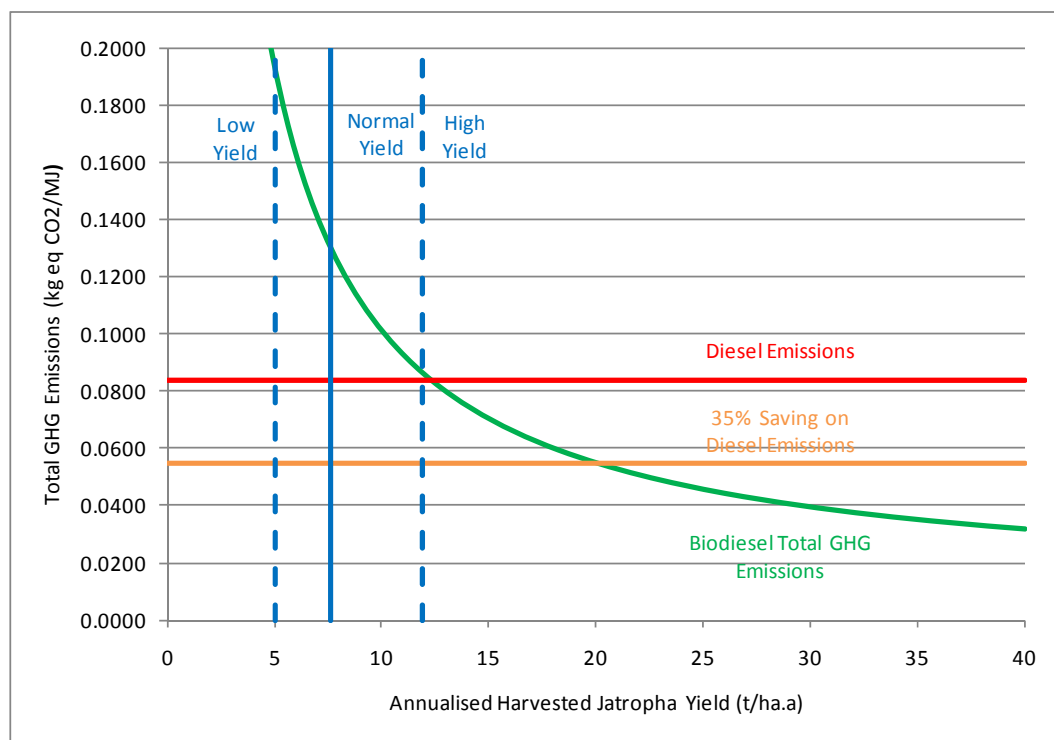


Figure D.13 Variation of Total Greenhouse Gas Emissions for Biodiesel for Transport in Kenya Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction and Transesterification Plant

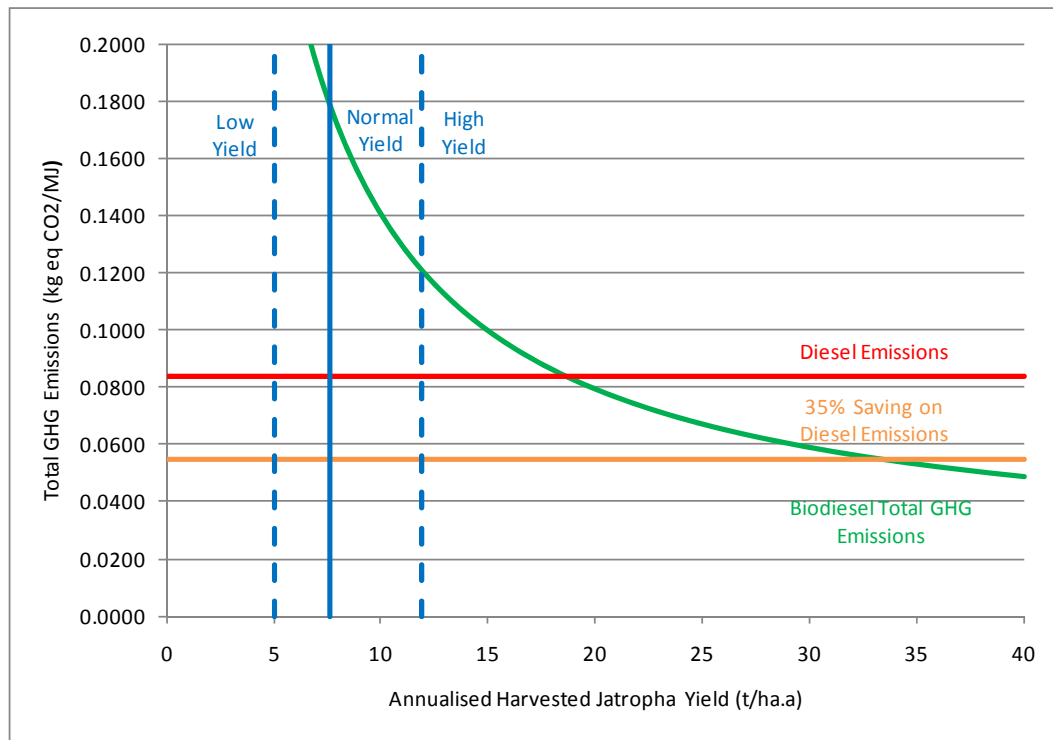


Figure D.14 Variation of Total Greenhouse Gas Emissions for Biodiesel for Transport in Kenya Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

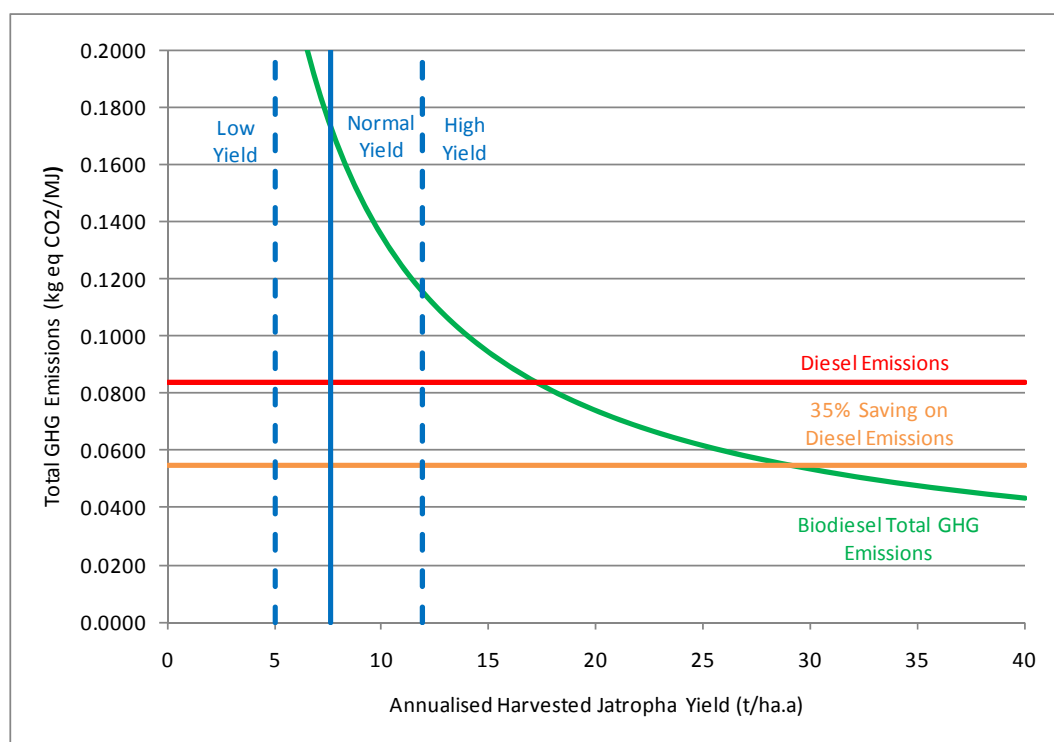


Figure D.15 Variation of Total Greenhouse Gas Emissions for Biodiesel for Transport in Kenya Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Biomass-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

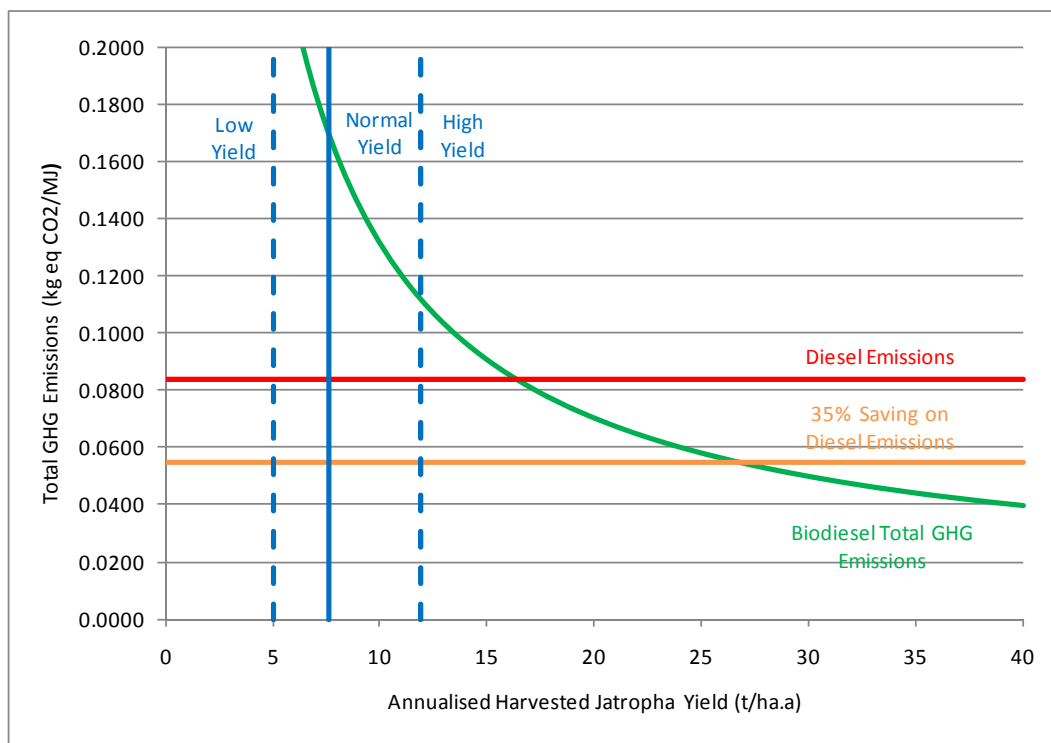


Figure D.16 Variation of Total Greenhouse Gas Emissions for Biodiesel for Transport in Kenya Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction and Transesterification Plant

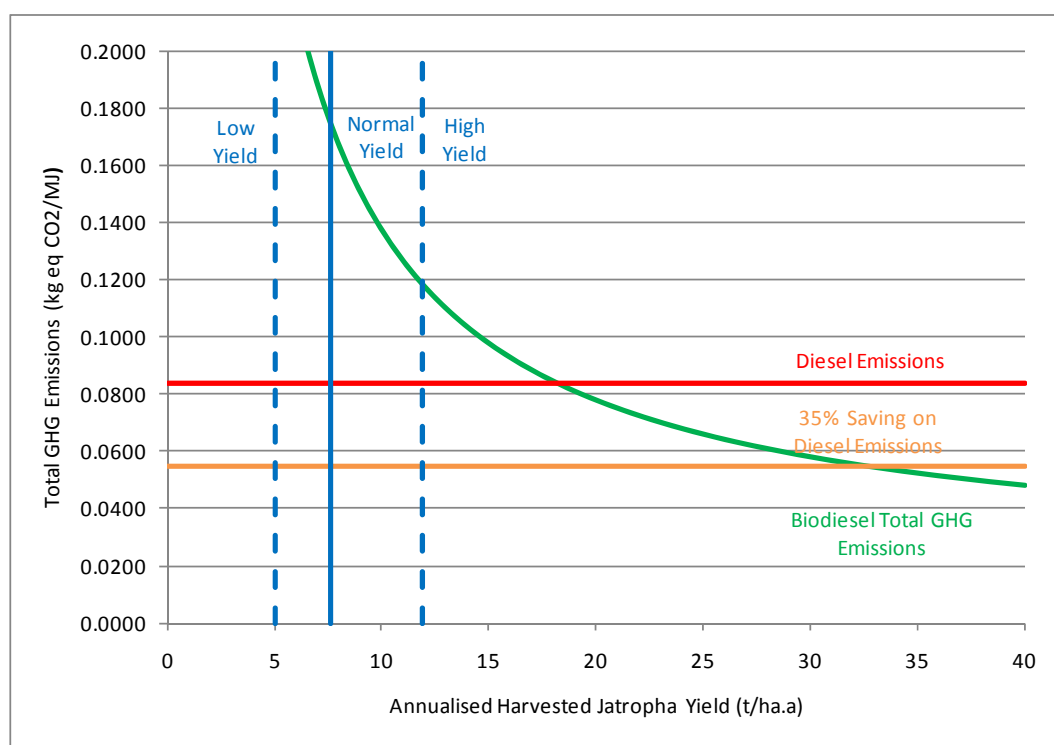


Figure D.17 Variation of Total Greenhouse Gas Emissions for Biodiesel for Transport in Kenya Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

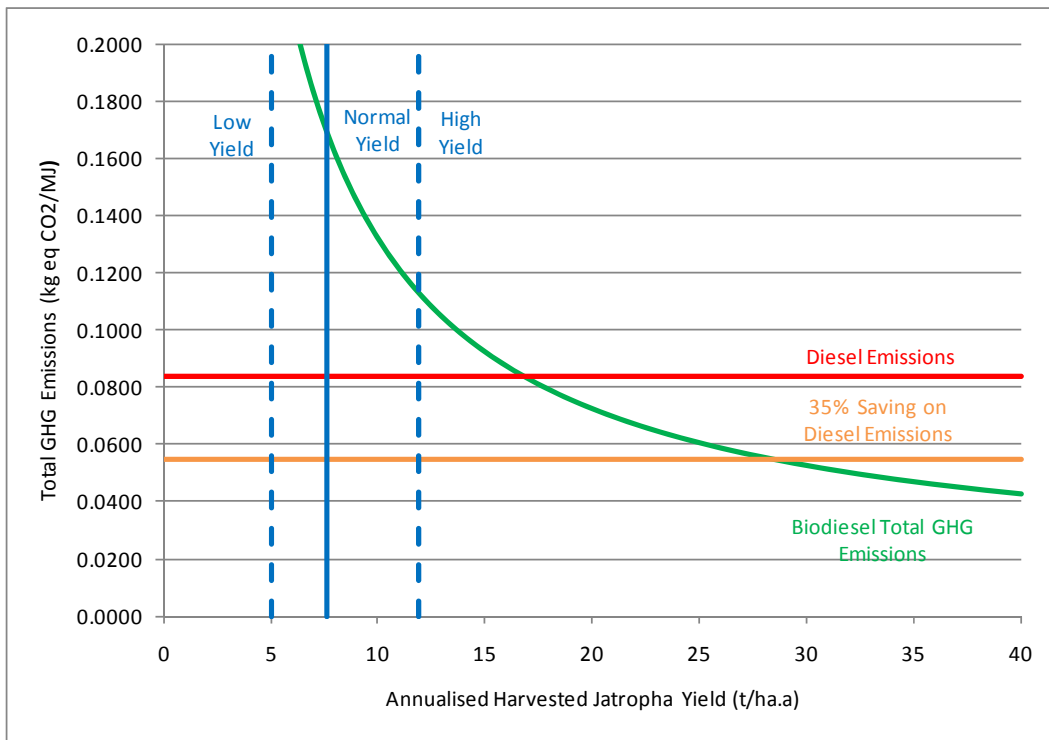
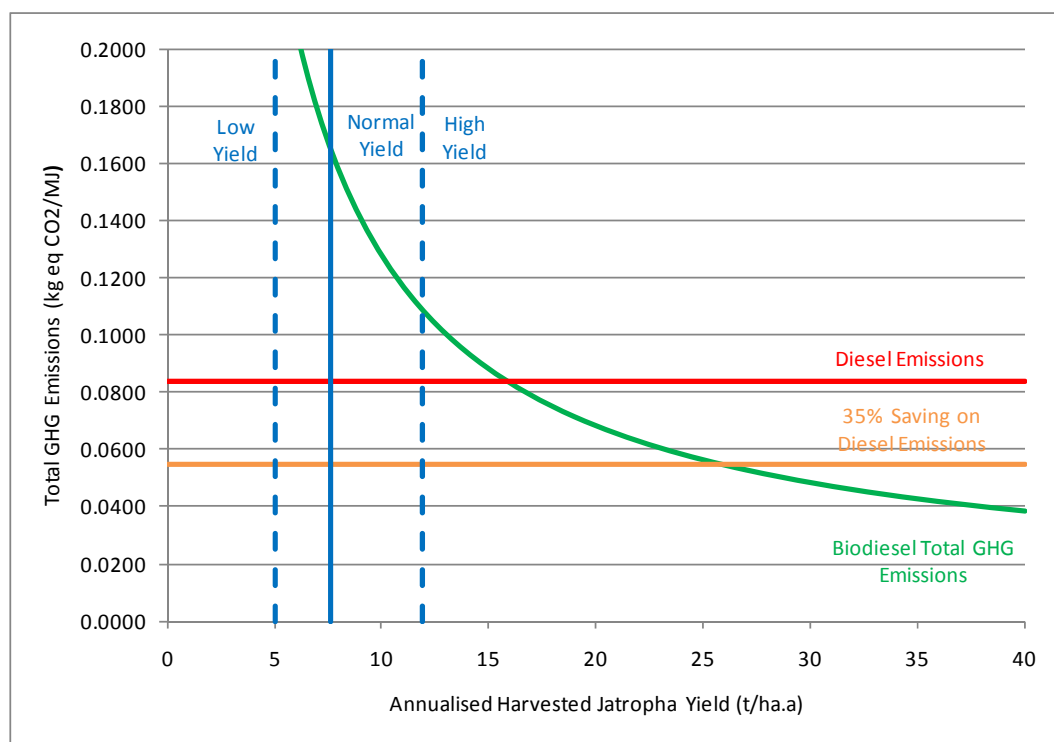


Figure D.18 Variation of Total Greenhouse Gas Emissions for Biodiesel for Transport in Kenya Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Zero Nitrogen Fertiliser Application and Biomass-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant



APPENDIX E: Dakatcha Biodiesel Production and Use for Cogeneration in Italy

Results generated from RSPBKenya_jat_v6.xls and recorded in RSPB Kenya Biofuels GHG dLUC 04.xls with the following assumptions:

Dried jatropha seed oil content = 35%

Jatropha conversion ratio = 3.945 t dried jatropha seed/t biodiesel

Net calorific value of biodiesel = 37,200 MJ/t

Figure E.1 Variation of Total Greenhouse Gas Emissions for Biodiesel for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Scrubland, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction and Transesterification Plant

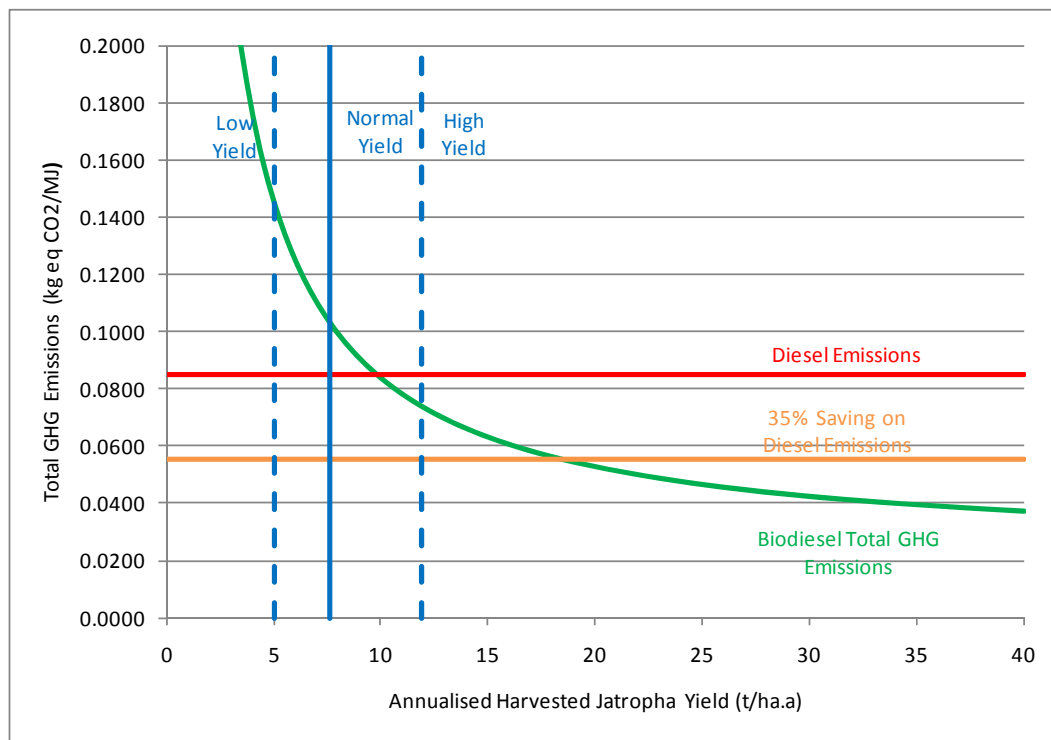


Figure E.2 Variation of Total Greenhouse Gas Emissions for Biodiesel for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Scrubland, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

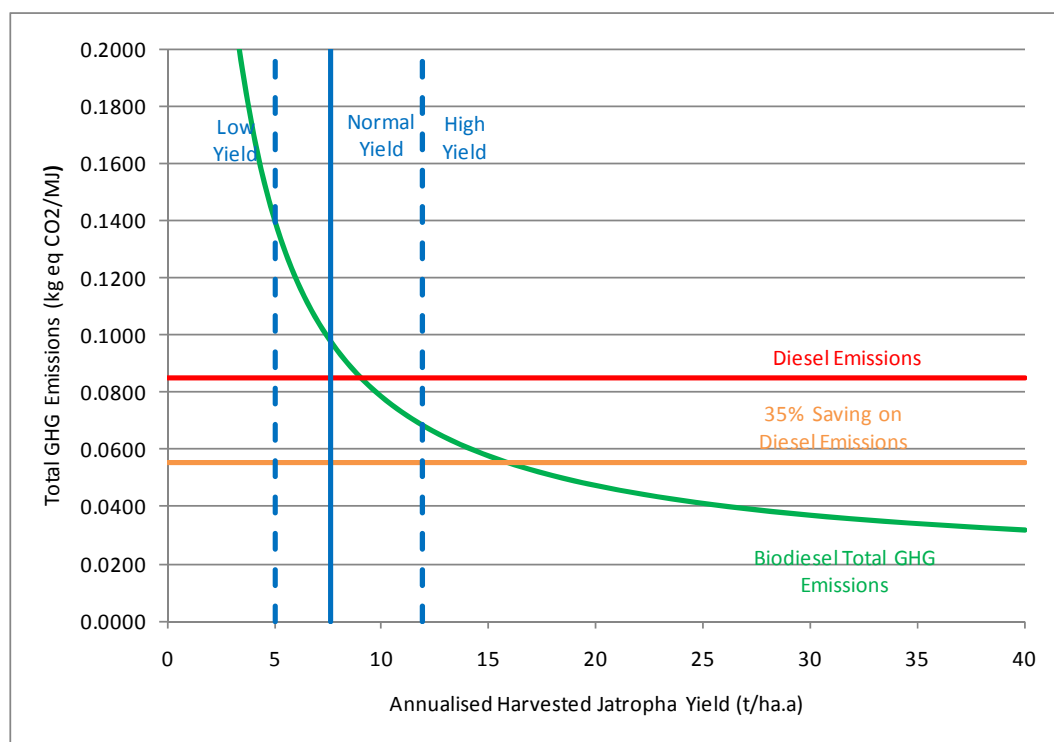


Figure E.3 Variation of Total Greenhouse Gas Emissions for Biodiesel for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Scrubland, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Biomass-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

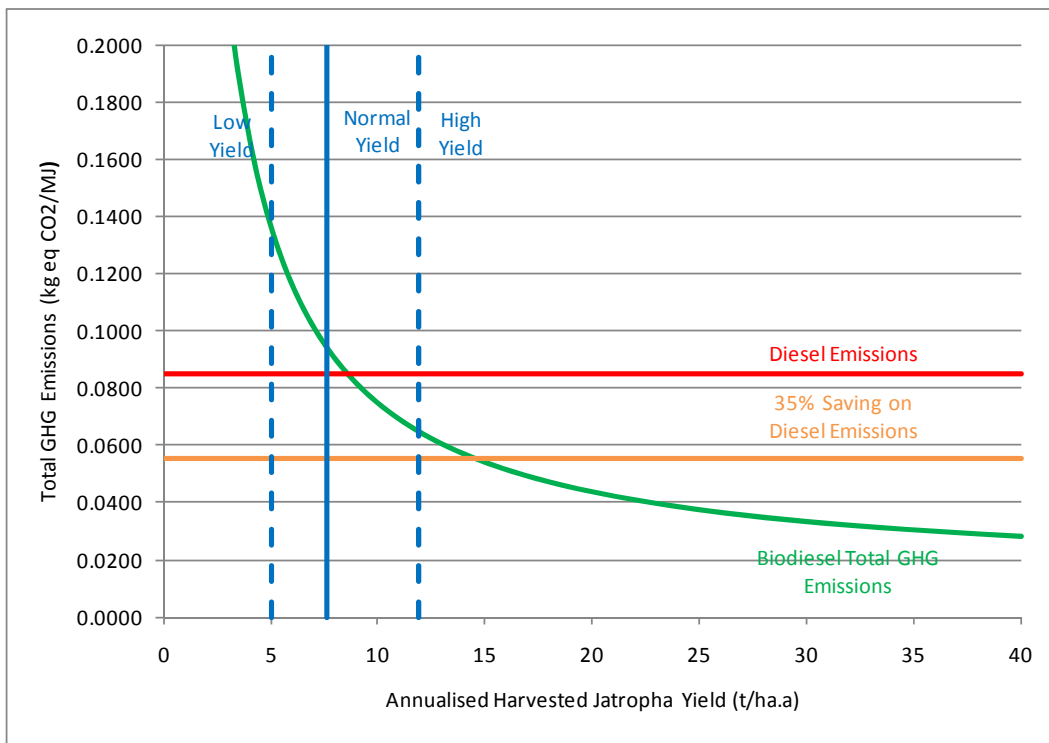


Figure E.4 Variation of Total Greenhouse Gas Emissions for Biodiesel for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Scrubland, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction and Transesterification Plant

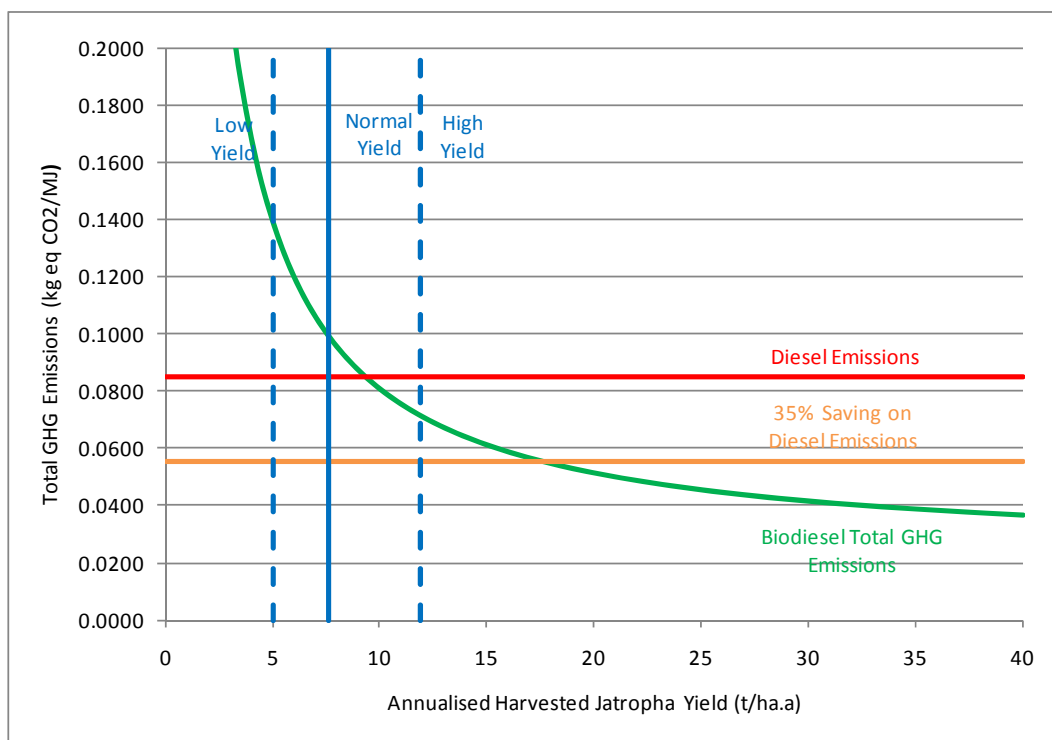


Figure E.5 Variation of Total Greenhouse Gas Emissions for Biodiesel for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Scrubland, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

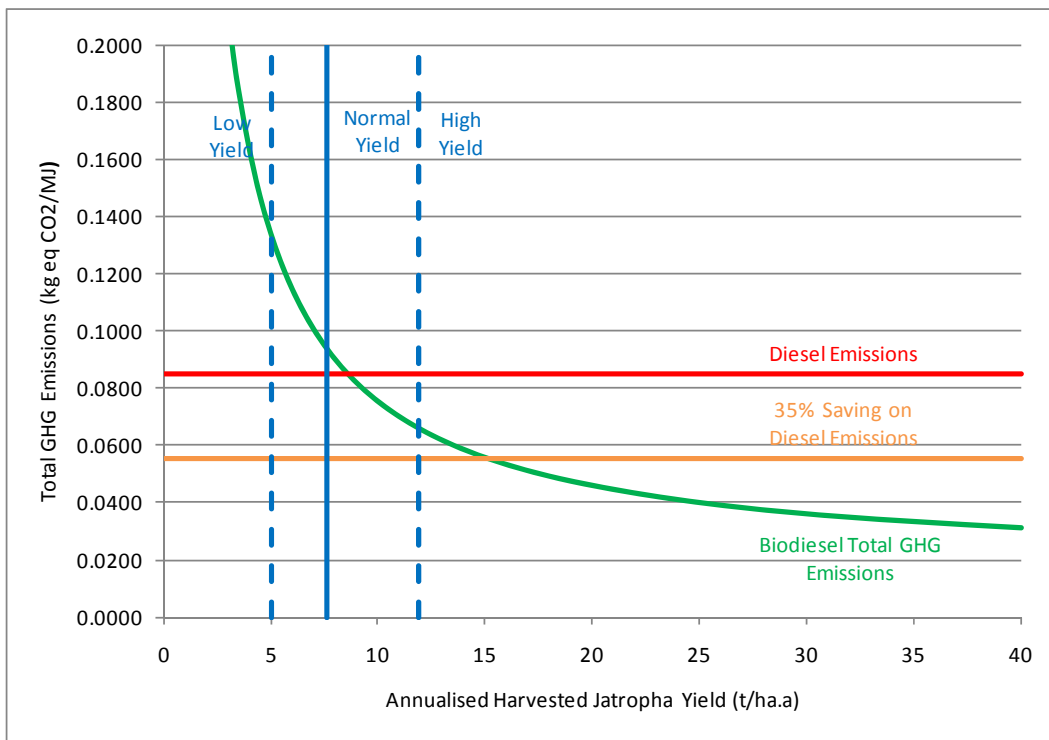


Figure E.6 Variation of Total Greenhouse Gas Emissions for Biodiesel for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Scrubland, Zero Nitrogen Fertiliser Application and Biomass-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

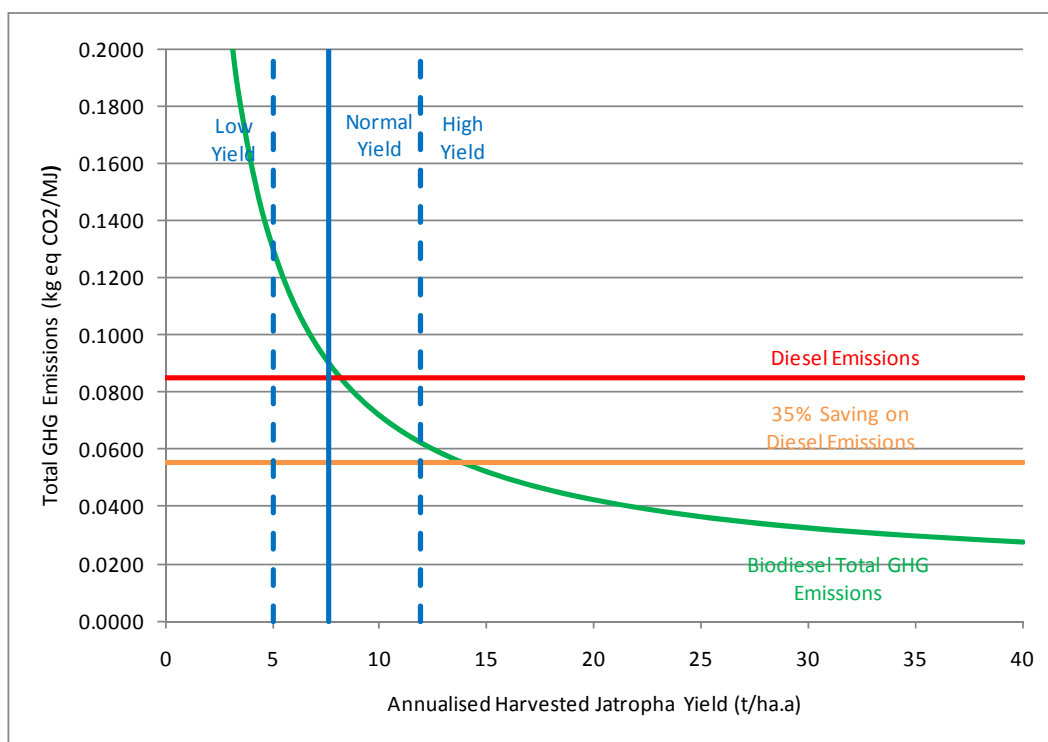


Figure E.7 Variation of Total Greenhouse Gas Emissions for Biodiesel for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction and Transesterification Plant

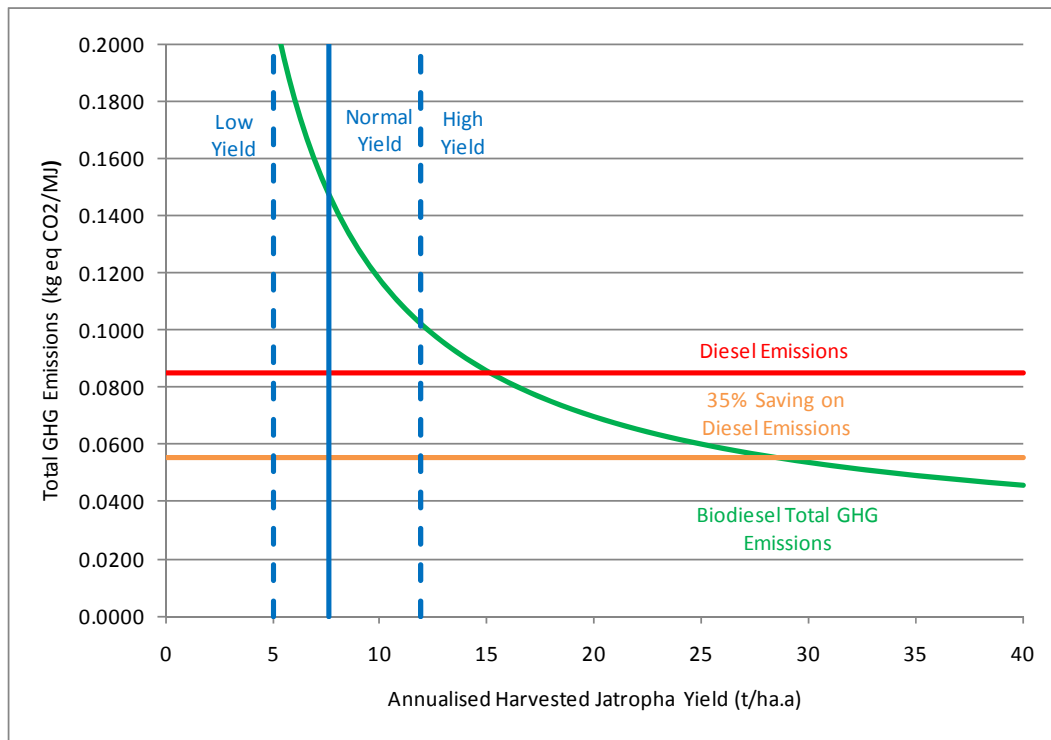


Figure E.8 Variation of Total Greenhouse Gas Emissions for Biodiesel for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

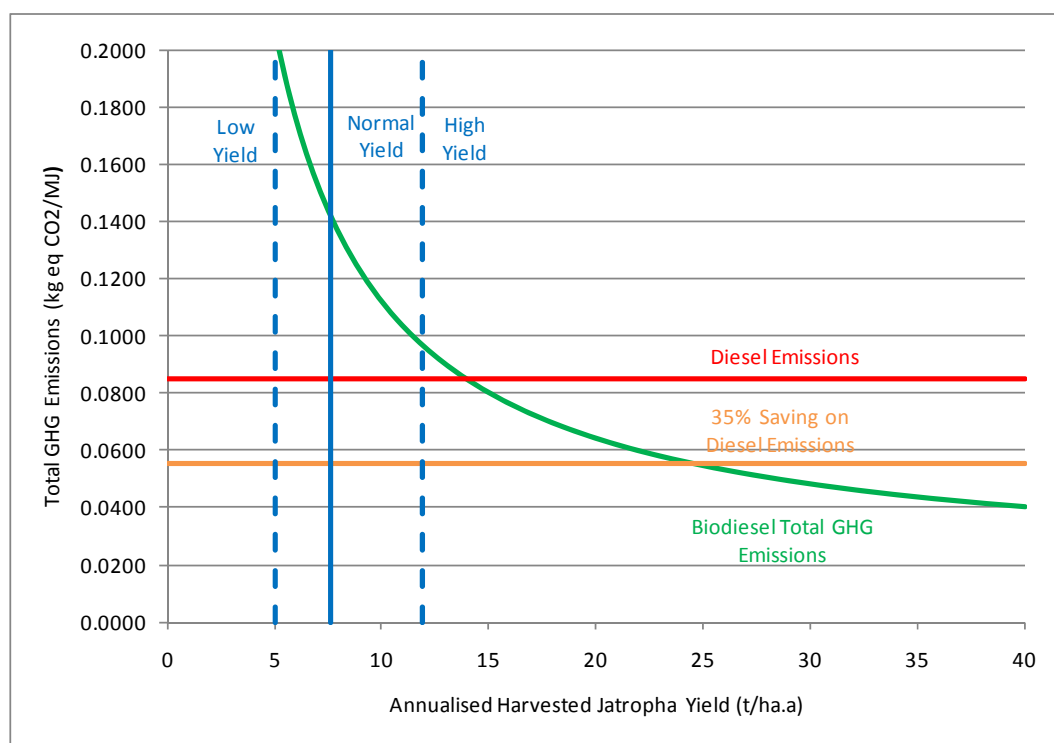


Figure E.9 Variation of Total Greenhouse Gas Emissions for Biodiesel for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Biomass-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

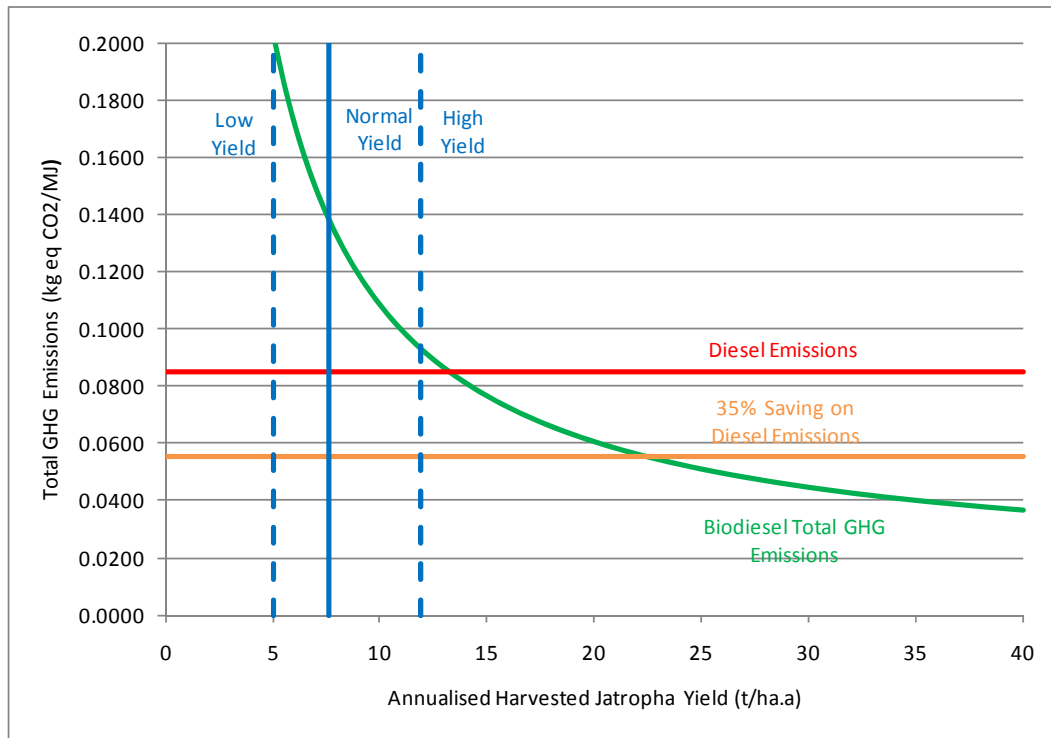


Figure E.10 Variation of Total Greenhouse Gas Emissions for Biodiesel for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction and Transesterification Plant

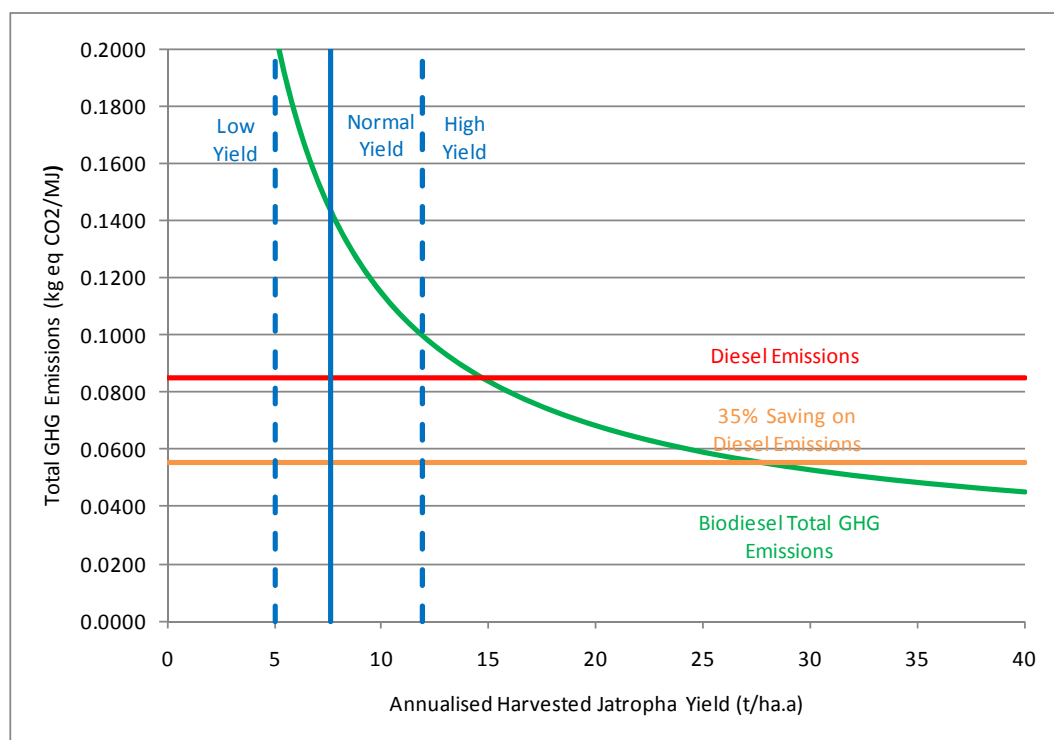


Figure E.11 Variation of Total Greenhouse Gas Emissions for Biodiesel for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

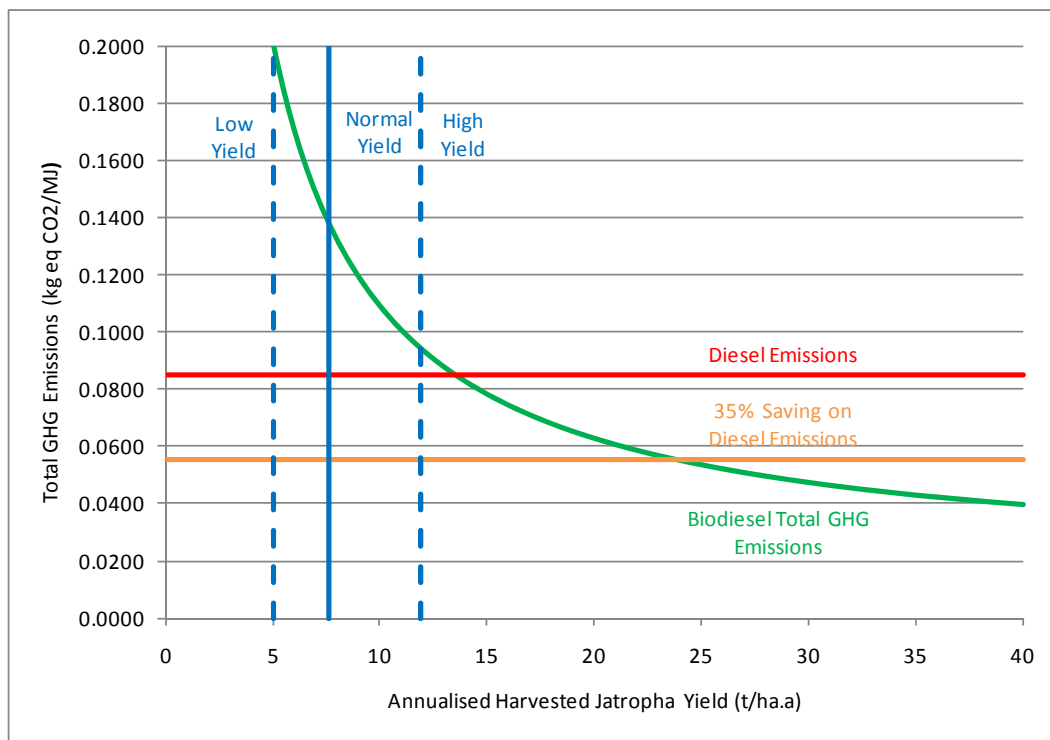


Figure E.12 Variation of Total Greenhouse Gas Emissions for Biodiesel for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Dry Forest with Greater than 30% Canopy Cover and Shifting Cultivation with Shortened Fallow, Zero Nitrogen Fertiliser Application and Biomass-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

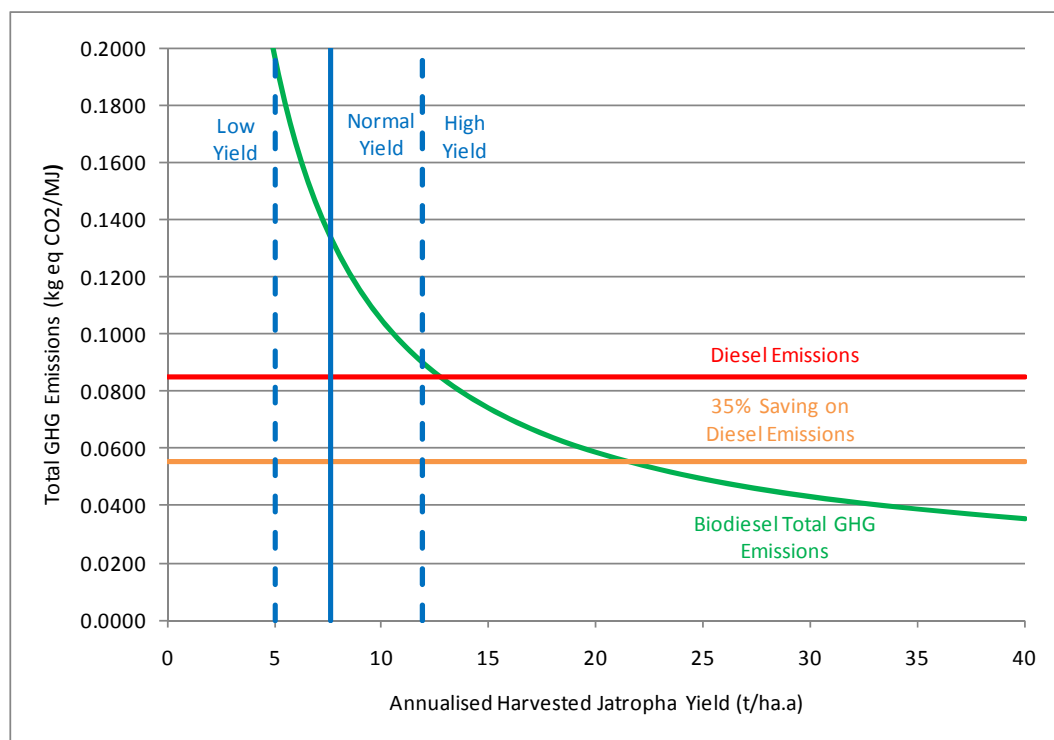


Figure E.13 Variation of Total Greenhouse Gas Emissions for Biodiesel for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction and Transesterification Plant

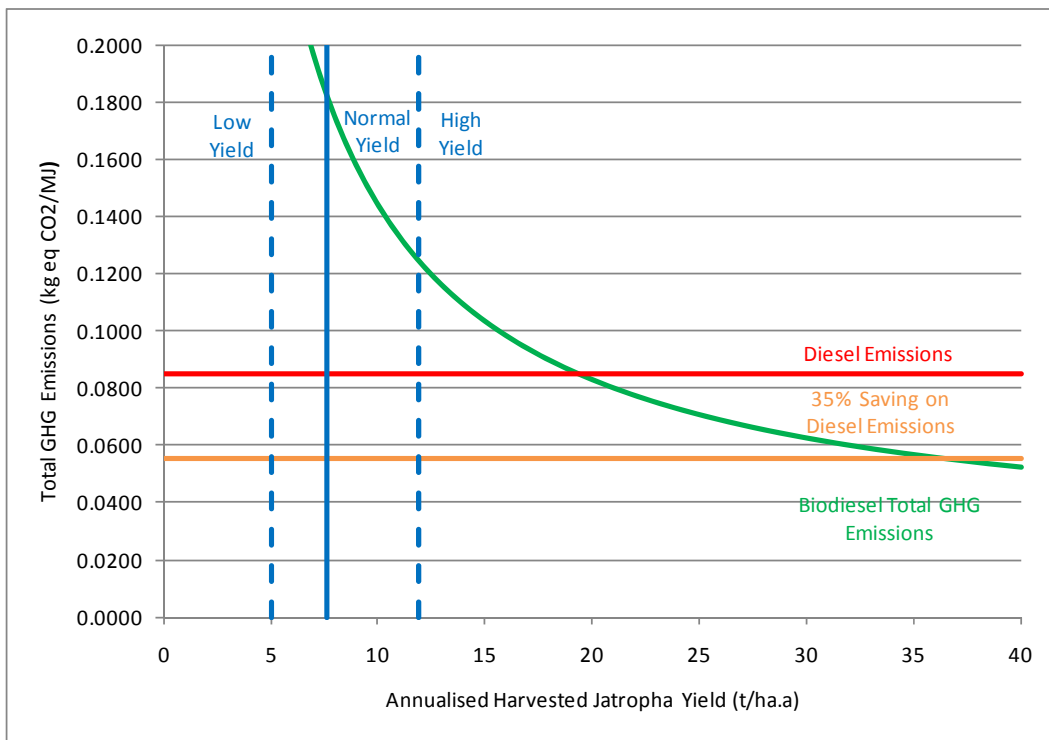


Figure E.14 Variation of Total Greenhouse Gas Emissions for Biodiesel for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

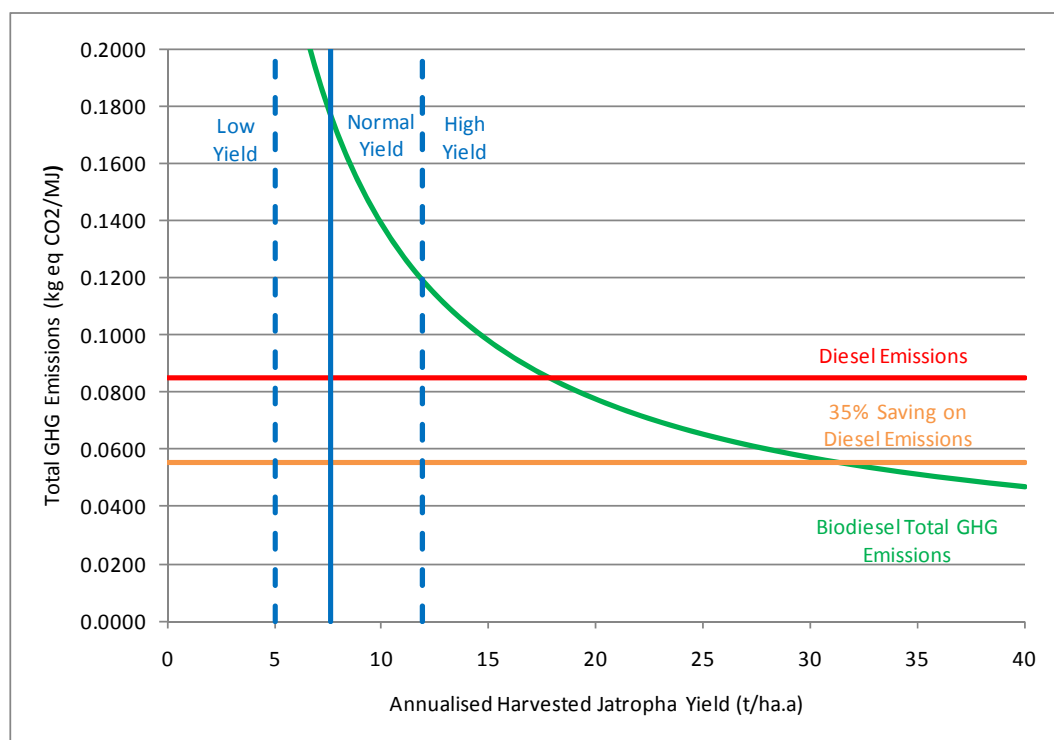


Figure E.15 Variation of Total Greenhouse Gas Emissions for Biodiesel for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Fixed Nitrogen Fertiliser Application Rate of 81 kg N/ha.a and Biomass-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

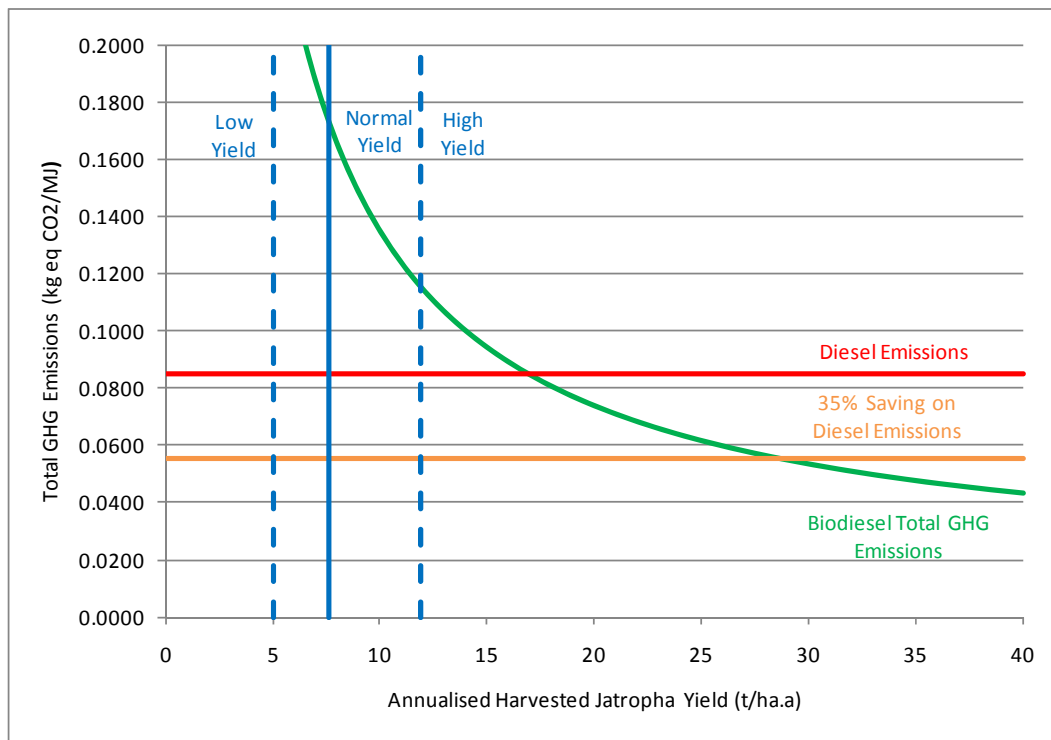


Figure E.16 Variation of Total Greenhouse Gas Emissions for Biodiesel for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Boiler and Grid Electricity for Oil Extraction and Transesterification Plant

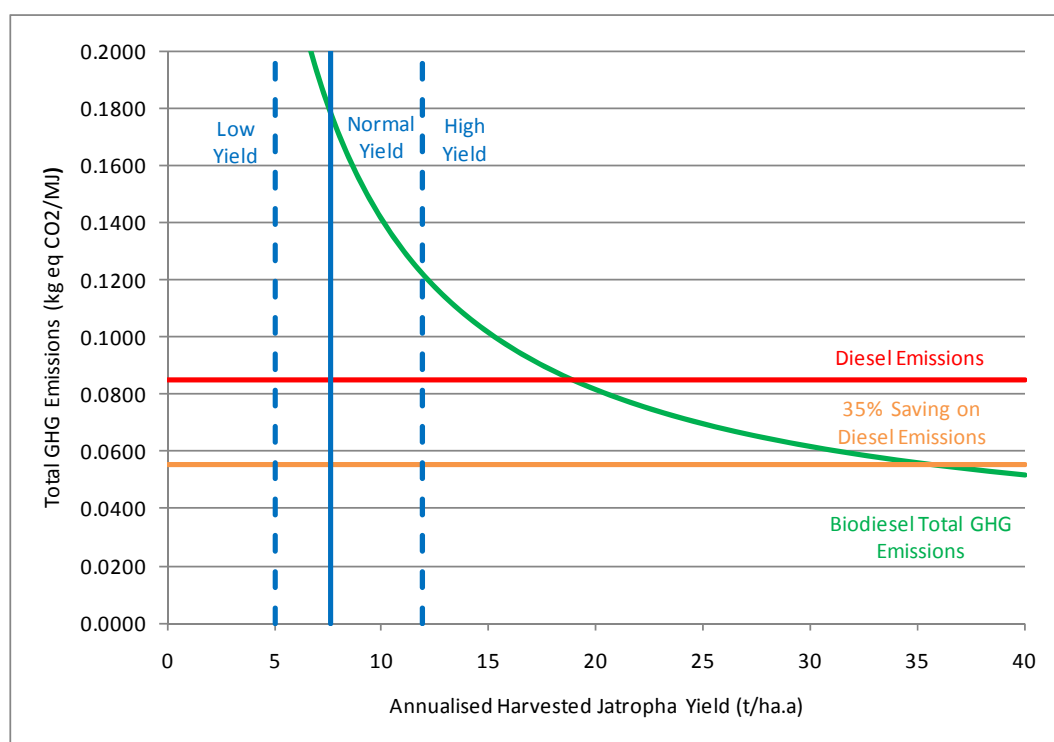


Figure E.17 Variation of Total Greenhouse Gas Emissions for Biodiesel for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Zero Nitrogen Fertiliser Application and Fuel Oil-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

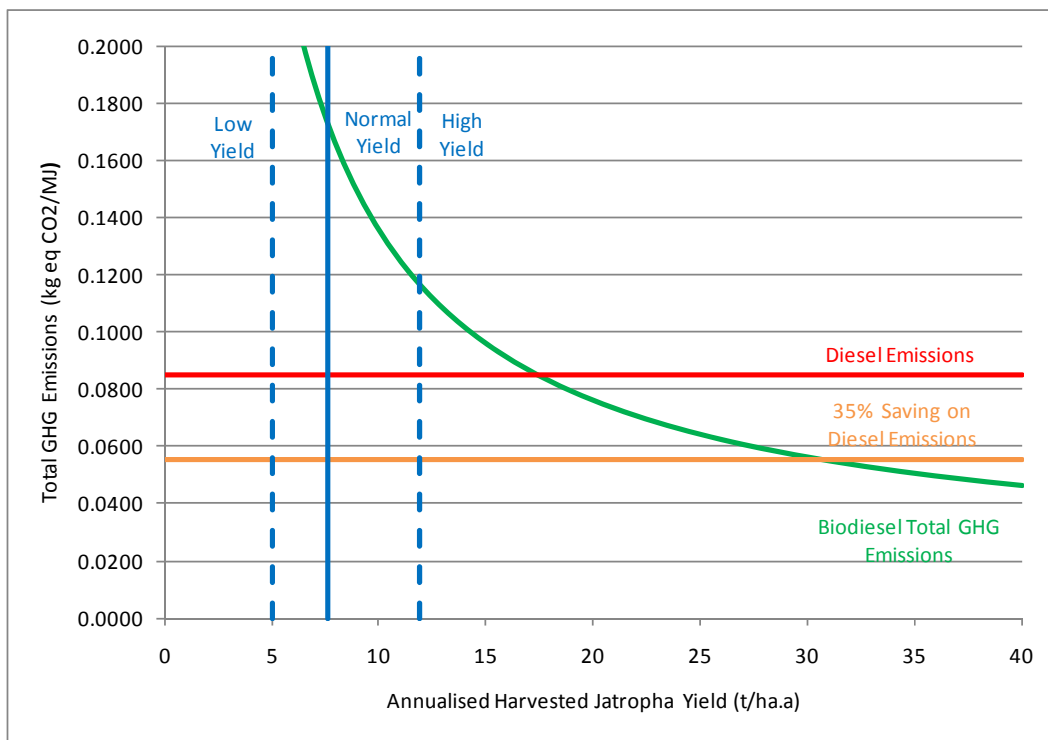


Figure E.18 Variation of Total Greenhouse Gas Emissions for Biodiesel for Cogeneration in Italy Produced from Jatropha with Yield: Conversion from Non-degraded Forest with Greater than 30% Canopy Cover, Zero Nitrogen Fertiliser Application and Biomass-fired Combined Heat and Power Unit for Oil Extraction and Transesterification Plant

