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Geospatial based biofuels suitability assessment in Ethiopia

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Due to the rising demands of fuels combined with efforts in reducing greenhouse gas emission, countries all over the world are looking for alternative clean energy sources such as biofuel. Ethiopia imports a huge amount of fuel each year and to supplement its energy needs efforts are underway for biofuel development. Despite this, comprehensive assessments of the suitable sites for biofuel feedstocks are lacking. This study is designed to map suitable sites for selected biodiesel feedstocks (Jatropha, Castor, Croton, and Cottonseed) and bioethanols (Cassava and Sweet Sorghum) and estimating the potential productions in Ethiopia. The spatial representations of the requirements (Soil, Elevation, Rainfall, and Temperature) of the feedstocks were created and processed to eventually map the suitable sites. About 16, 30, 28, 34%, 6, 83% of the country is highly suitable (HS) for Jatropha, Castor, Croton, Cassava, Cottonseed and Sweet Sorghum, respectively. The suitability assessments were also made by excluding environmentally sensitive lands (e.g marshy areas, parks, wildlife sanctuaries and forests) and areas that can compromise crop production (e,g, cultivated lands). Accordingly, 6, 9, 7, 10, 2 and 36% of the country remains HS, thus large scale biofuel production can be conducted without affecting food security and the environment in these areas. Hence, the country can produce up to 355.44 and 225.09 billion liters of biodiesel and bioethanol, respectively, returning up to 53 billions USD overall revenue.

Key words: Biofuel, biodiesel, bioethanol, suitability, HS.

INTRODUCTION

The negative externality and rising prices of fossil fuel have resulted in ever-increasing efforts to look for alternative energy sources, and the particularly due emphasis is given for biodiesel and bioethanol in order to contribute to solving economic, environmental and social problems (Nadew, 2014). In addition to its ample water resource as energy sources, Ethiopia is viewed as one of the most suitable countries in Africa for tapping other renewable sources of energy including biodiesel and bio-ethanol because of its location and favorable climate condition (Zenebe et al., 2014).

Ethiopian government developed Climate Resilient Green Economy (CRGE) Strategy in the year 2011 having the vision to achieve middle-income status by 2025 in a

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sustainable way. The biofuels industry in Ethiopia can contribute a lot to ensuring rural food security by diversifying the livelihood source (Gebreebziabher et al., 2013). Besides its economic benefit, biodiesel and bioethanol production has a great role in the reduction of GHGs and shifting towards clean energy. Among the four abatement potential of the transport sector, which are stated in CRGE strategy, one of the green growth initiatives is changing the fuel mix using a combination of adding biodiesel to the diesel mixture, increasing the amount of ethanol in the gasoline mixture, and promoting the adoption of hybrid and plug-in electric vehicles has a combined abatement potential of nearly 1.0 Mt CO2e (FDRE, 2011). Biofuel could be mixed together into transport fuels, and replace some of the kerosene currently used for cooking predominantly in urban areas and for lighting in rural areas that lack electricity (Steve et al., 2011).

Findings of Zenebe et al. (2014) revealed that bioethanol production in Ethiopia is quite viable whereas the viability and competitiveness of biodiesel production will largely depend on the cost and price of feedstock. The negative effect of biodiesel and bioethanol production might be high as biofuel production competes with the use of land for traditional crops (Tadele et al., 2013). This, in turn, could affect the food security of the rural community. Allocation of land for biodiesel development should not affect the livelihoods of pastoralists in the lowland areas; and in the highlands, it should be coordinated with other farming activities without jeopardizing the farmers' food production needs. In addition, direct and/or indirect land-use changes that result from their cultivation can cause emissions due to carbon losses in soils and biomass and could reverse any eventual greenhouse gas (GHG) reduction benefit (Achten and Verchot, 2011).

Little researches have been conducted regarding suitability analysis of biodiesel and bioethanol in Ethiopia. Even though those studies tried to map suitability of biofuel in Ethiopia, they lack the sustainable issue since the suitable lands may be laid on productive farmland, wetland or other sensitive areas. Habtamu (2014), in the study suitability analysis for Jatropha curcas production using spatial modeling methods recognized that from the total land of the country 15.07% (166,082 km2), 76.57% (844,040 km2) and 8.36% (92,114 km2) of the land as highly suitable, moderately suitable and not suitable for Jatropha production, respectively. However, his study did not exclude the sensitive areas. Production of Jatropha even on highly suitable land could have a negative effect on food security as well as on the environment so that its production would not be sustained. The results of suitability analysis would be good when sensitive lands are excluded otherwise even those suitable areas would have negative externalities. Environmental effects of biofuel crop cultivation include reduced wetland areas and their functions, declining water quantity, declining water quality and increased risk of eutrophication and it ends up with biodiversity loss and ecosystem damage (Sven and Offermans, 2008). The exact nature and magnitude of these effects depend on the biofuel crop characteristics and the agricultural practices applied. To this end, this research assessed sustainable biodiesel and bioethanol suitability in Ethiopia by taking into account sensitive lands that can affect food security and areas that require protection include croplands, forest lands, national parks and wildlife sanctuaries and water bodies.

Biofuel is a liquid fuel produced from biomass; it excludes treatments of solid biomass as a source of energy. The two most important biofuels are ethanol and biodiesel. Ethanol is manufactured from the microbial conversion of biomass materials through fermentation whereas, biodiesel is oil extracted from oil seeds by mechanical crushing or solvent extraction (MoME, 2007).

General agronomic requirements of biofuel feedstocks

Biodiesels

Among the many species, which yield as a source of energy in the form of biodiesel, Jatropha (Jatropha curcas) has been identified as the most suitable oil seed bearing plant due to its various favorable attributes like hardy nature, short gestation period, adaptability in wide range agro-climatic conditions, high oil recovery and quality of oil, etc (Pranab, 2011). Jatropha curcas grows in tropical and sub tropical regions and in lower altitudes of 0-500 meters above sea level. It can survive with as little as 250 to 300 mm of annual rainfall; at least 600 mm is needed to flower and fruit. The optimum rainfall for seed production is considered between 1000 and 1500 mm (FAO, 2010). Optimum temperatures are between 20 °C and 28°C. The best soils for Jatropha are aerated sands and loams of at least 45 cm depth (Gour, 2006).

Another crop species for biodiesel production, Castor (Ricinus communis) is growing in different localities in Ethiopia and it is an indigenous plant. The suitable condition for castor crop growing zone is between 1600 and 2600 m.a.s.l and rainfall distribution between 600 and 700mm with warm and dry climatic condition. The yield is estimated between 260 and 1250 kgs per hectare (MoME, 2007).

Cotton (Gossypium hirsutum and Gossypium herbaceum) is also considered in this study for the production of biodiesel and it can be grown in areas where mean annual rainfall ranges from 600 – 1300 mm and temperature 20-30OC. It also grows well on elevation up to 1400 m a.s.l with black cotton soils (ICRAF, 2009). It requires a long, sunny growing season, is not frost tolerant, and prefers well-drained loose soils. Nowadays, cotton seed oil is mainly used in industries to produce soap and glycol lubricants besides being used as edible oil. Therefore, compared to soybean oil, palm oil, and colza oil, cottonseed oil is an appropriate raw material of biodiesel because of its advantages in origin and uses (Niu et al., 2010). The biodiesel comes as a new source of remuneration for the cotton crop.

According to ICRAF (2009), croton (Codiaeum variegatum) is also used to extract biodiesel. It is cultivated in areas with mean annual rainfall of 800-1900 mm and mean temperature of 11-26oC. Altitude 1200-2450 and light deep and well-drained soils are very suitable for croton production.

Bioethanols

Cassava (Manihot esculenta Crantz) is a tropical root crop, requiring at least 8 months of warm weather to produce a crop. In drought prone areas it loses its leaves to conserve moisture, producing new leaves when rains resume. It takes 18 or more months to produce a crop under adverse conditions such as cool or dry weather. Cassava does not tolerate freezing conditions. It tolerates a wide range of soil pH 4.0 to 8.0 and is most productive in full sun (Legese and Gobeze, 2013). In Ethiopia, cassava was introduced to drought prone areas of Southern part of the country such as Amaro, Gamogofa, Sidama, Wolaita, Gedeo and Konso primarily to fill food gap for subsistence farmers due to the failure of other crops as a result of drought. In these areas, farmers usually grow cassava in small irregular scattered plots either sole or intercropped mainly with taro, enset, maize, haricot bean and sweet potato (Eyasu, 1997). Cassava finds the most favorable growing conditions in humid-warm climates at temperatures of between 25 - 29°C and precipitations of between 1000 - 1500 mm which ideally should be evenly distributed (Owwueme, 2014). Cassava likes light, sandy loam soils with medium soil fertility and good drainage.

Sweet sorghum (*Sorghum bicolor* (L.) Moench) is an alternative energy crop supported by the European Commission under the 7th Framework Programme to exploit the advantages as a potential energy crop for bioethanol production. For developing countries, it provides opportunities for the simultaneous production of food and bioenergy, thereby contributing to improved food security as well as increased access to affordable and renewable energy sources (Khawaja, 2014). Sweet sorghum needs moderate rainfall and an average temperature of 80 – 90oF for grain production and maturity. It can be grown in a variety of soils heavy and light alluviums, red, gray, yellow loams and also sandy soils (Panhwar, 2005).

METHODS

Description of the study area

Ethiopia is a tropical country located in the Eastern parts of Africa. It extends between 330E - 480 E longitude and 30 N - 150N latitude (Figure 1) and has a total area of 112,867,369.97 Ha. The country is a home of about 104.4 million people [36]. Its landscape is dissected into two parts by the Great East African Rift. The landscape is characterised by undulating terrain and rugged topography and constitutes diverse agroecological zones supporting a variety of fauna and flora. Ethiopia's climate is typically tropical in the south-eastern and north-eastern lowland regions, but much cooler in the large central highland regions of the country. Mean annual temperatures are around 15-20˚C in these high altitude regions, whilst 25-30˚C in the lowlands. Most parts of Ethiopia experience one main wet season (called 'Kiremt') from mid-June to mid-September (up to 350mm per month in the wettest regions) when the ITCZ (Inter Tropical Convergence Zone) is at its northern-most position. Parts of northern and central Ethiopia also have a secondary wet season of sporadic, and considerably lesser, rainfall from February to May (called the 'Belg'). The southern regions of Ethiopia experience two distinct wet seasons which occur as the ITCZ passes through this more southern position. The March to May'Belg' season is the main rainfall season yielding 100-200 mm per month, followed by a lesser rainfall season in October to December called 'Bega' (around 100mm per month). The eastern most corner of Ethiopia receives very little rainfall at any time of year.

Customizing agronomic requirements of biofuel feedstocks

The suitability assessments made are made for selected biodiesel and bioethanol feedstocks. In the biodiesel category, the feedstocks include, Jatropha (Jatropha curcas), Castor (Ricinus communis), Cottonseed (Gossypium hirsutum and Gossypium herbaceum), Croton (Codiaeum variegatum) while the bioethanols include, Cassava (Manihot esculenta Crantz) and Sweet sorghum (*Sorghum bicolor* (L.) Moench).

The environmental requirements of these feedstocks for optimum growth are identified after thoroughly reviewing the literature (Table 1). The requirements are related to soil, rainfall, temperature, elevation. Since the biofuel production areas should not affect food security by consuming the croplands, the land use /land cover conditions of the country were also considered in the suitability analysis. With respect to each of these environmental factors, the cutoff points for suitable and non-suitable values vary considerably from place to place. As a result of this, the cutoff points are determined by giving more weight to researchers' findings conducted in Ethiopian and the neighboring regions. Thus, all factors were classified as suitable and given a value of 1 and the non-suitable as 0. Table 1 indicates the customized crop requirements for each feedstock.

Despite this, we acknowledge the the subjectivity that might be introduced in setting the cutoff points.

Spatial data acquisition and representation of agronomic requirements

The data needed for representing agronomic requirements are collected from different sources. The data include rainfall, temperature, land use/land cover, soil, elevation, National Parks and Wildlife Sanctuaries (Table 2).

Land cover/land use, national parks and wildlife sanctuaries

In line with the countries priority of food security and promoting climate resilient green economy (CRGE), biofuel productions should not compromise food security and protected lands. Such areas include croplands, forests, water bodies, marshy areas, national

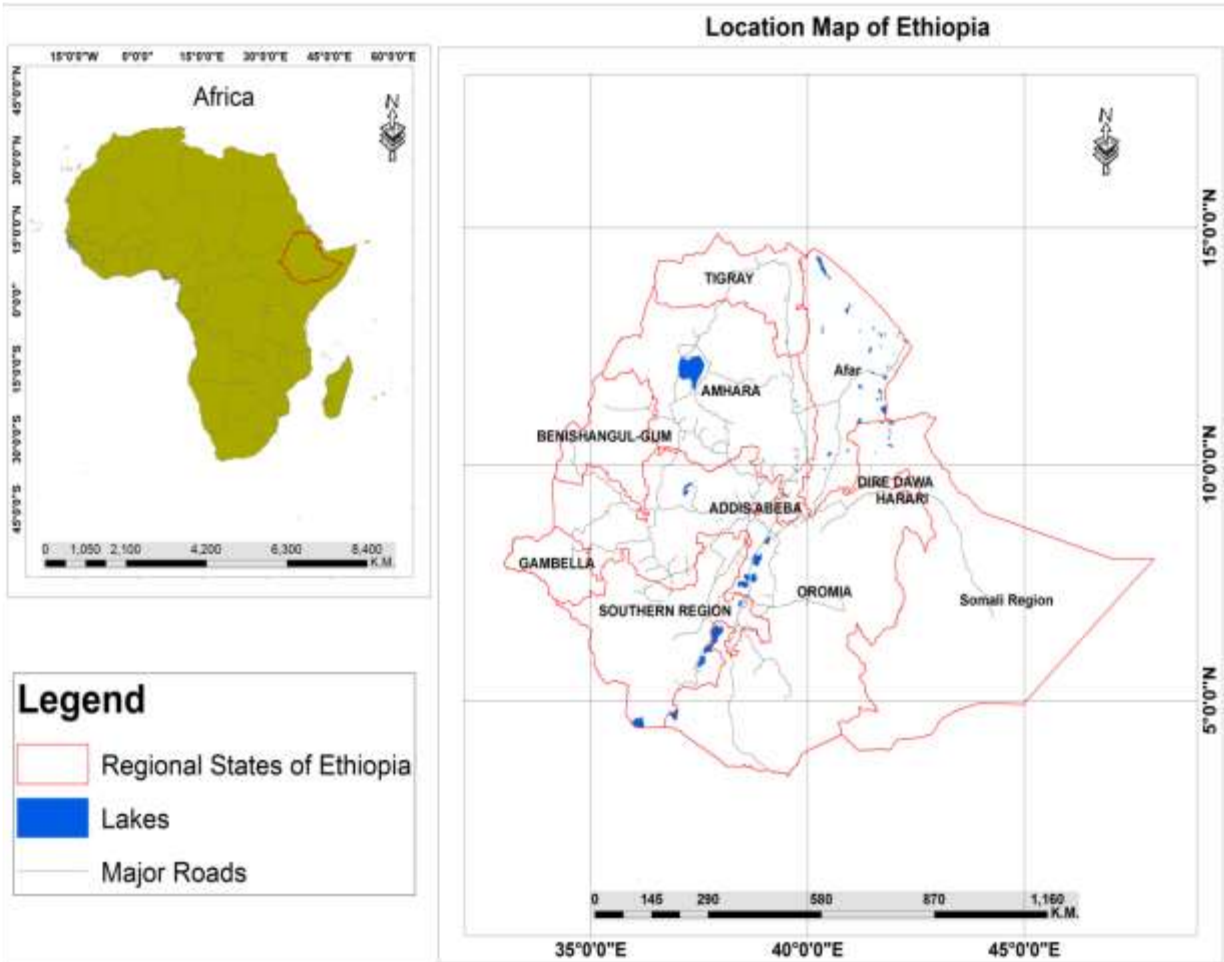


Figure 1. Location map of the study area.

parks and wildlife sanctuaries and are categorized as sensitive lands.

The land cover map of the country is derived from mosaics of Landsat satellite images processed through supervised classification of the maximum likelihood classifier. The classification and mapping were conducted by the Ethiopian Mapping Agency. The croplands and forested areas acquired from the land cover map were considered in the suitability analysis to address food security and environmental protection.

These data were acquired from the Ethiopian National Parks Wildlife Authority in a polygon shape file format.

Rainfall and Temperature

These data were provided by the Ethiopian Ministry of Agriculture and it was the result of interpolation of the long-term rainfall and temperature records of the countries metrological stations. The data were available in vector data model form (polygon shapefile).

Elevation

The elevation data were acquired from the shuttle radar topographic mission (SRTM) and were available from the United States Geological Survey (USGS) website (https://www.usgs.gov). It provides Digital Elevation Model (DEM) at a spatial resolution of 30 m for free for any part of the world. The DEM Scenes covering the country were downloaded and mosaic to get the DEM representing the country.

Soil

The Food and Agriculture Organization (FAO) has mapped the major soils of the country but the methodology and the year of publication were not documented either in the metadata or elsewhere but the year of publication was estimated to be around 2007. The data had no soil texture information while the agronomic requirements are related to soil texture information. Hence the soil textures were inferred from the major soil types.

As the data were found from different sources, they had different coordinate systems, formats and sometimes different extents. All the data were preprocessed to overcome the anomalies through geometrical co-registration and format integration among themselves. For example, all the data were projected into WGS 1984 geographic coordinate system and co-registered to align points of the same location together. As raster data models are suitable for overlay operations, which is the GIS analysis used to evaluate the suitability in this study, vector data formats were

Table 1. Customized crop requirements.

	Jatropha		
Factors	**Suitable**	**Not suitable**	**Source**
Rainfall	0 – 1500 mm	>1500	FACT. 2007; Grass. 2009; Heller. 1996
Temperature	17-28^{0}C	<=17 or >28	Gour. 2006; Wu et al.. 2009; Achten and Verchot. 2011
Elevation	0 – 1500 m	< 0 or >1500	Gour. 2006; ICRAF. 2009; Achten and Verchot. 2011; Wiesenhutter. 2003
Soil	Well-drained sandy and loam soils	Other soil types	Gour. 2006; Ouwens. 2007; Brittaine and Lutaladio. 2010; Achten and Verchot. 2011
Castor			
Factors	Suitable	Not suitable	Source
Rainfall	400-2000mm	<400 and>2000	ICRAF. 2009; MoME. 2007; Muok and Kallback. 2008
Temperature	7-38^{0}C	<7 and >38	ICRAF. 2009; Muok and Kallback. 2008
Elevation	300-1800	<300 and >1800	ICRAF. 2009; MoME. 2007; Muok and Kallback. 2008
Soil	Well-drained. sandy loam	Other Soil types	ICRAF. 2009; Muok and Kallback. 2008
Croton			
Factors	Suitable	Not Suitable	Source
Rainfall	800-1900mm	<400 and >1900	ICRAF. 2009; Muok and Kallback. 2008
Temperature	11-38^{0}C	<11 and >38	ICRAF. 2009; Muok and Kallback. 2008
Elevation	1200- 2450m	<1200 and >2450	ICRAF. 2009; Muok and Kallback. 2008
Soil	Light deep and well-drained soil	Other soil types	ICRAF. 2009; Muok and Kallback. 2008
Cottonseed			
Factors	Suitable	Not Suitable	Source
Rainfall	600-2000mm	<600 and >2000	EIA. 2012
Temperature	11-30^{0}C	<11 and >30	ICRAF. 2009; EIA. 2012
Elevation	0-2000m	<0 and > 2000	>>
Soil	Black cotton soil	Other soil types	>>
Cassava			
Factors	Suitable	Not Suitable	Source
Rainfall	500-2000	<500 and>2000	DFID. 2014; Dejene. 2006; Onwueme. 1978a; ICRAF. 2009
Temperature	15-30^{0}C	<15 and >30	>>
Elevation	0-2000 m	<0 and >2000	ICRAF. 2009; DFID. 2014
Soil	Except salty and poorly drained soil		>>
Sweet sorghum			
Factors	Suitable	Not Suitable	Source
Rainfall	300-2000mm	<600 and >2000	ICRAF. 2009
Temperature	11-40^{0}C	<11 and >40	ICRAF. 2009
Elevation	0- 2700m	<0 and > 3000	ICRAF. 2009; DFID. 2014

converted into raster form.

GIS model and suitability analysis

Six separate GIS model for suitability mapping were developed for the six biofuel feedstocks considered. Each model constitutes data representing the agronomic requirements and procedures to bring all the requirements together through intersection overlay analysis (Figure 2). The model is built in the model builder environment in ArcGIS10.2. The intersection overlay takes the following form.

$$\mathbf{Suitability} = \sum_{n=0}^{1} \boldsymbol{Soil} \cap \sum_{n=0}^{1} \boldsymbol{Temp} \cap \sum_{n=0}^{1} \boldsymbol{RF} \cap \sum_{n=0}^{1} \boldsymbol{Elev}$$

Table 2. Data source and types.

Data	Source	Format
Soil (2007)	FAO. 2007	Shapefile
Land use/land cover 2013	Ethiopian Mapping Agency	Tiff/Raster
Rainfall	Ethiopian Meteorological Agency	Shapefile
Temperature		Shapefile
Elevation (30m Resolution)	USGS	Raster DEM
National parks and wildlife sanctuaries (2014)	Ethiopian National Parks Wildlife Authority	Shapefile

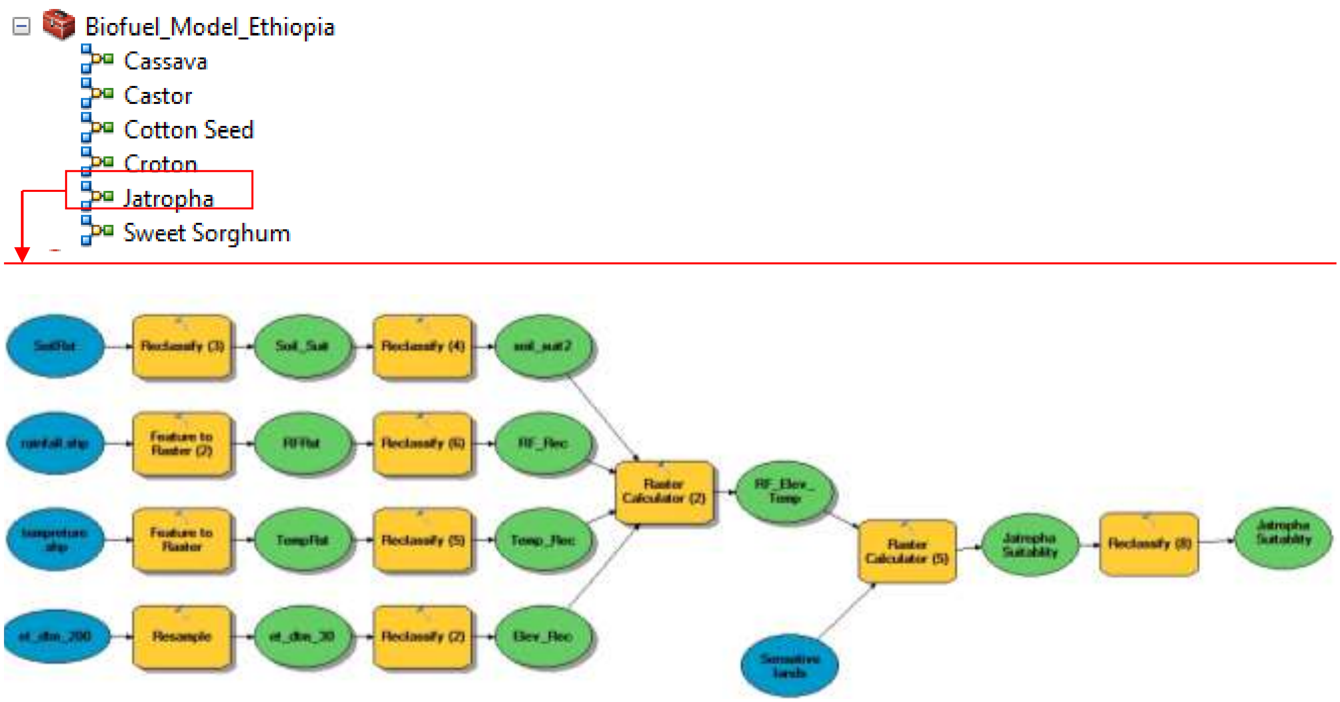


Figure 1. GIS-based model for biofuel suitability assessment.

The suitability had five values of 4,3,2,1 and 0, which indicate the number of requirements met among all the factors considered. These values then classified into suitability classes as, 4=Highly Suitable, 3 = Moderately Suitable, 2 and 1= Marginally Suitable and 0=Not Suitable.

The suitability analysis is conducted two times for each biofuel feedstocks, the first one is without excluding sensitive lands and the second one is by considering the sensitive lands as a constraint areas for biofuel production. This will create an insight into the decision and policy makers about the overall potential of the country for biofuel production and production without affecting food security and environmental production.

Despite this, biofuel production can also be conducted at small scale in general land uses classified as croplands by planting biofuels at the boundaries of the croplands as an agroforestry practice without affecting food production. In this case, it would have multiple benefits beyond biofuel production as it can serve as soil and water conservation, ameliorate the local climate and serve as boundary demarcation of fragmented farmlands common in the Ethiopian landscapes.

Once the suitability map is produced for each biofuel feedstock, the maps were validated visually by overlaying the location of existing plantations. This validation technique, however, limited to Jatropha as some of the plantation areas for this feedstock were known. The overall methodological workflow of the suitability mapping and analysis is summarized in Figure 3.

RESULTS AND DISCUSSION

The biofuels suitability distribution varies spatially all over the country and there are also considerable variations across the biofuels feedstocks under consideration though some of them exhibit a similar pattern of distribution. For Jatropha, the western Benishangula and Amhara regional states, north and central Tigray, southern parts of southern nations and nationalities people (SNNP), the western and eastern escarpments of the rift valley region and eastward side of the southwestern highlands of the country are HS. The visual inspection of the actual Jatropha

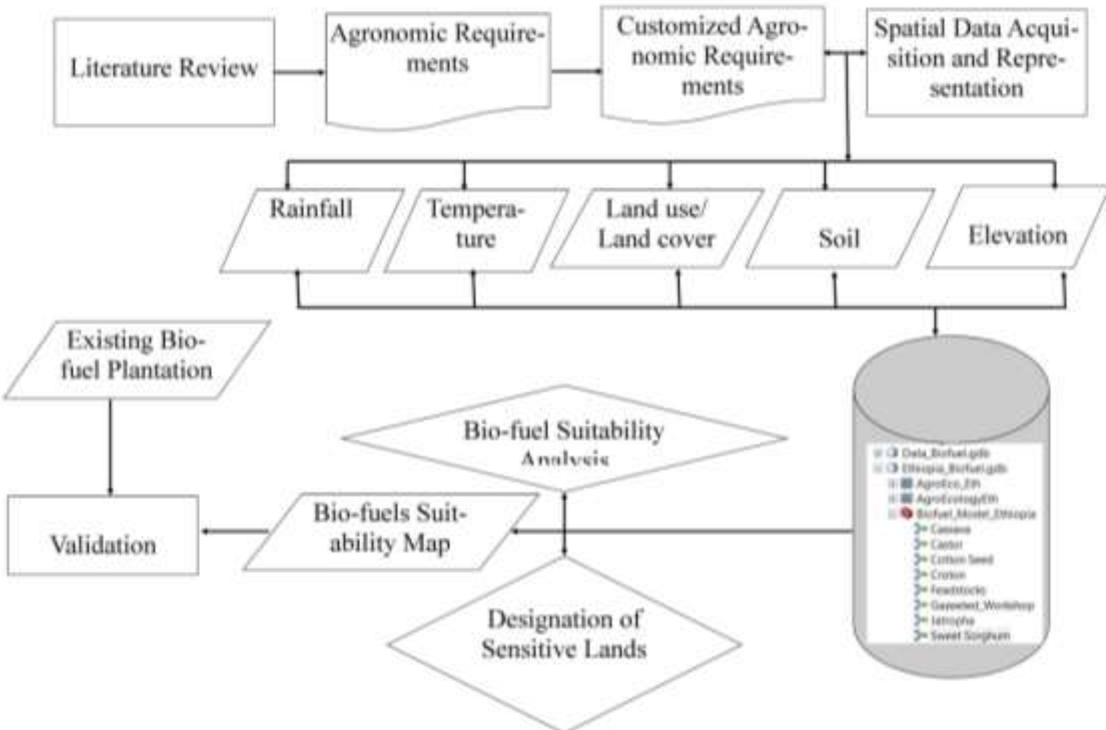


Figure 3. Methodological workflow of the suitability assessment.

growing regions well fits with the suitability map produced for Jatropha. For example, there is a plantation of Jatropha along the western escarpments of the rift valley regions including such woredas as Kalu, Bati, Kobo, Guba lafto, Alamata and Chefie Golana. In the Northern and central Tigray region, Kola Temben and Abergele are some of the woredas growing Jatropha and are mapped as HS areas. The existing plantation areas for other biofuel feedstock, however, were unavailable to validate the suitability map with. However, the HS area for castor takes the similar pattern with that of Jatropha, except the HS area is stretched in all directions. Croton grows well in most central parts of the country, western Oromiya and the southeastern highlands of the country. Cassava and castor can grow well in similar environmental conditions. That is why both of these feedstocks have a similar spatial pattern of HS areas. The only difference is that the environmental requirements of cassava are met in more areas than castor in the country. Cottonseed grows in patchy areas in western Amhara and Tigray, Northern Somalia and North Western SNNP. Sweet sorghum grows in the highland and lowland areas of the country. Except eastern and southern Somalia, northeastern Afar and some parts of Oromiya and SNNP, it grows well in all parts of the country (Figure 4 a-f).

Most of the sensitive lands such as croplands are dominating the central parts of the country and the remaining forests which are part of the sensitive lands are concentrated in the western and southwestern highlands of the country. In all the biofuel feedstocks considered, HS areas in these regions will become none suitable because of food security and environmental protection issues.

Among all the biofuels, most of the study area is Highly Suitable (HS) for sweet sorghum by covering about 93 m Ha. Cassava, castor, croton, Jatropha and Cottonseed being the other biofuels that most of the country is HS and constitutes about 38, 33, 31, 18, and 6 m Ha of the study area, respectively (Table 3). As compared to other regional states, Oromiya is the region where the largest HS areas are available for all the biofuels under considerations. This is directly proportional to its areal coverage of the region.

The HS area left when sensitive lands are excluded from the biofuel assessment is considerably reduced. Only About 15,11,10,8,7 and 2 m Ha lands of the country is HS for sweet sorghum, castor, cassava, Jatropha, and cottonseed, respectively. Except Somali region where the largest HS area for sweet sorghum is available, for all other biofuels the largest HS area is found in Oromiya regional state (Table 4). The results of the suitability assessments are presented in Tables 3 and 5 and Figures 4 and 5.

Ethiopia imports fuel on average at the expense of 768 million USD per annum and this covers 77% of the total export earnings. The demand for fuel will increase when

Table 3: Overall Suitability of Biofuels in the Country

Biodiesel	REGION	NS		MaS		MoS		HS	
		Overall (Ha)	%	Overall(Ha)	%	Overall(Ha)	%	Overall(Ha)	%
Jathropha	TIGRAY	10,937.13	1.50	1,673,348.00	3.94	2,329,596.00	4.51	1,596,224.00	8.86
	AMHARA	428,129.68	58.81	7,330,680.00	17.25	5,151,536.00	9.98	2,427,476.00	13.47
	BENISHANGUL-G	0.00	0.00	359,548.00	0.85	1,816,168.00	3.52	2,693,016.00	14.95
	OROMIA	223,946.10	30.76	12,936,512.00	30.45	14,445,668.00	27.98	7,919,636.00	43.96
	DIRE DAWA	0.00	0.00	160	0.00	34,592.00	0.07	115,992.00	0.64
	HARARI	0.00	0.00	2,704.00	0.01	32,716.00	0.06	4004	0.02
	SNNP	64,750.17	8.89	5,027,852.00	11.83	4,649,692.00	9.01	1,908,724.00	10.59
	GAMBELLA	0.00	0.00	1,370,516.00	3.23	1,112,288.00	2.15	71,356.00	0.40
	AFAR	282.89	0.04	4,016,556.00	9.45	4,593,872.00	8.90	726,020.00	4.03
	SOMALI	0.00	0.00	9,718,548.00	22.87	17,466,568.00	33.83	555,140.00	3.08
	ADDIS ABEBA	0.00	0.00	52,616.00	0.12	0	0.00	0	0.00
Total		**728045.97**	**100.00**	**42,489,040.00**	**100.00**	**51,632,696.00**	**100.00**	**18,017,588.00**	**100.00**

Biodiesel	REGION	Overall (Ha)	%	Overall (Ha)	%	Overall (Ha)	%	Overall (Ha)	%
Castor	TIGRAY	0	0.00	660,878.00	2.73	2,333,369.00	4.25	2,614,767.00	7.80
	AMHARA	0	0.00	2,160,379.00	8.93	7,859,884.00	14.33	5,318,597.00	15.87
	BENISHANGUL-G	0	0.00	13,909.00	0.06	893,630.00	1.63	3,960,758.00	11.82
	OROMIA	2763.670057	0.94	4,939,143.00	20.40	16,298,514.00	29.72	14,285,672.00	42.61
	DIRE DAWA	0	0.00	0	0.00	12,316.00	0.02	138,402.00	0.41
	HARARI	0	0.00	68	0.00	21,628.00	0.04	17,703.00	0.05
	SNNP	0	0.00	2,215,860.00	9.15	4,473,813.00	8.16	4,960,856.00	14.80
	GAMBELLA	0	0.00	1,077,220.00	4.45	987,298.00	1.80	488,920.00	1.46
	Afar	153,517.87	52.18	3,843,039.00	15.88	4,611,206.00	8.41	730,305.00	2.18
	SOMALI	137,938.43	46.88	9,274,509.00	38.32	17,320,916.00	31.58	1,007,033.00	3.00
	ADDIS ABEBA	0	0.00	20,561.00	0.08	31,997.00	0.06	0	0.00
Total		**294,219.97**	100.00	**24,205,566.00**	**100.00**	**54,844,571.00**	**100.00**	**33,523,013.00**	**100.00**

Biodiesel	REGION	NS		MaS		MoS		HS	
		Overall (Ha)	%	Overall(Ha)	%	Overall(Ha)	%	Overall(Ha)	%
Croton	TIGRAY	0	0	922,472.00	1.76	2,149,056.00	7.5	2,538,476.00	7.99
	AMHARA	35,261.97	100	3,446,688.00	6.57	4,395,888.00	15.35	7,456,660.00	23.48
	BENISHANGUL-G	0	0	591,084.00	1.13	3,180,244.00	11.11	1,095,720.00	3.45
	OROMIA	0	0	9,466,680.00	18.05	10,221,372.00	35.69	15,837,192.00	49.87
	DIRE DAWA	0	0	8,444.00	0.02	81,084.00	0.28	61,168.00	0.19
	HARARI	0	0	0	0	848	0	38,532.00	0.12
	SNNP	0	0	2,586,688.00	4.93	5,144,380.00	17.96	3,917,272.00	12.33
	GAMBELLA	0	0	1,742,868.00	3.32	802,180.00	2.8	7,776.00	0.02
	Afar	0	0	8,509,864.00	16.23	780,968.00	2.73	49,412.00	0.16
	SOMALI	0	0	25,131,632.00	47.93	1,863,676.00	6.51	751,220.00	2.37
	ADDIS ABEBA	0	0	29,092.00	0.06	17,676.00	0.06	5,796.00	0.02
Total		**35,261.97**	100	**52,435,512.00**	**100**	**28,637,372.00**	**100**	**31,759,224.00**	**100**

	REGION	Overall (Ha)	%	Overall(Ha)	%	Overall(Ha)	%	Overall(Ha)	%
Cassava	TIGRAY	0	0.00	707,952.00	2.68	1,790,788.00	3.75	3,111,264.00	8.04
	AMHARA	35,289.78	99.18	3,734,996.00	14.12	4,615,420.00	9.68	6,948,820.00	17.96
	BENISHANGUL-G	0	0.00	10,220.00	0.04	836,012.00	1.75	4,020,816.00	10.39
	OROMIA	0	0.00	5,598,620.00	21.17	13,517,384.00	28.34	16,409,240.00	42.41
	DIRE DAWA	0	0.00	0	0	8,680.00	0.02	142,016.00	0.37
	HARARI	0	0.00	0	0	9,408.00	0.02	29,972.00	0.08

Table 3: Contd.

	SNNP	0	0.00	1,880,704.00	7.11	4,093,584.00	8.58	5,674,052.00	14.67
	GAMBELLA	0	0.00	1,072,248.00	4.05	992,576.00	2.08	488,000.00	1.26
	Afar	292.1943749	0.82	3,990,124.00	15.09	4,616,808.00	9.68	732,992.00	1.89
	SOMALI	0	0.00	9,407,968.00	35.58	17,206,888.00	36.07	1,131,672.00	2.93
	ADDIS ABEBA	0	0.00	41,392.00	0.16	11,172.00	0.02	0	0
Total		**35,581.97**	100.00	**26,444,224.00**	**100**	**47,698,720.00**	**100**	**38,688,844.00**	**100**
Biodiesel	**REGION**	**NS**		**MaS**		**MoS**		**HS**	
		Overall (Ha)	**%**	**Overall(Ha)**	**%**	**Overall(Ha)**	**%**	**Overall(Ha)**	**%**
Cotton Seed	TIGRAY	316,400.79	16.01	1,464,628.00	2.39	3,239,408.00	7.57	576,636.00	8.35
	AMHARA	368,509.22	18.65	6,374,412.00	10.41	7,163,048.00	16.75	1,415,372.00	20.49
	BENISHANGUL-G	0	0.00	227,448.00	0.37	4,315,156.00	10.09	324,844.00	4.7
	OROMIA	356,417.74	18.04	14,919,784.00	24.37	17,200,884.00	40.22	3,032,536.00	43.89
	DIRE DAWA	0	0.00	8,724.00	0.01	141,972.00	0.33	0	0
	HARARI	0	0.00	8,668.00	0.01	30,712.00	0.07	0	0
	SNNP	247,858.18	12.54	4,233,096.00	6.91	6,231,616.00	14.57	976,816.00	14.14
	GAMBELLA	0	0.00	491,100.00	0.8	1,939,816.00	4.54	126,096.00	1.83
	Afar	686,592.04	34.75	7,691,276.00	12.56	880,216.00	2.06	68,680.00	0.99
	SOMALI	0	0.00	25,744,596.00	42.06	1,623,324.00	3.8	388,164.00	5.62
	ADDIS ABEBA	0	0.00	52,564.00	0.09	0	0	0	0
Total		**1,975,777.97**	100.00	**61,216,296.00**	**100**	**42,766,152.00**	**100**	**6,909,144.00**	**100**
	REGION	**Overall (Ha)**	**%**	**Overall(Ha)**	**%**	**Overall(Ha)**	**%**	**Overall(Ha)**	**%**
Sweet Sorghum	TIGRAY	0	0	39,621.20	1.72	118,944.00	0.71	5,451,600.00	5.81
	AMHARA	12,924.00	99.81	902,827.93	39.18	1,233,228.00	7.39	13,153,560.00	14.01
	BENISHANGUL-G	0	0	0	0.00	150,344.00	0.9	4,717,104.00	5.03
	OROMIA	24	0.19	572,924.37	24.86	3,224,276.00	19.32	31,706,148.00	33.78
	DIRE DAWA	0	0	0	0.00	0	0	150,696.00	0.16
	HARARI	0	0	0	0.00	0	0	39,380.00	0.04
	SNNP	0	0	118,794.36	5.16	1,695,508.00	10.16	9,881,852.00	10.53
	GAMBELLA	0	0	0	0.00	187,564.00	1.12	2,369,448.00	2.52
	Afar	0	0	667,651.33	28.97	1,665,436.00	9.98	6,998,968.00	7.46
	SOMALI	0	0	0	0.00	8,400,620.00	50.33	19,355,464.00	20.62
	ADDIS ABEBA	0	0	2,546.78	0.11	14,960.00	0.09	34,956.00	0.04
Total		**12,948.00**	**100**	**2,304,365.97**	100.00	**16,690,880.00**	**100**	**93,859,176.00**	**100**

Table 4. Average production per hectare and prices of the selected biofuel.

Biofuel types		**Yield (kg/Ha)**	**Production (Liter/Ha)**	**Price (USD/Ha)**	**Total Revenue (Billion USD)**	**Source**
Biodiesel	Jathropha	1590	400-2.200	600-3.300	4.27-23.49	(GTZ and MoAGK. 2008)
	Castor	838	1413	246	2.56	(ICRAF. 2009)
	Croton	2500	840	150	1.15	(FAO. 2008). (Anna and Giles. 2014)
	Cottonseed	273	325	160	2.29	(Anna and Giles. 2014)
Bio-ethanol	Sweet-Sorghum		3.00 0- 6.000	800	0.27	(FAO. 2008)
	Cassava		1.750-5.400	200	32.72	(FAO. 2008)

the economic growth of the nation increases. In order to ensure the country's continued development program and the national fuel security, it is important to increase fuel utilization and substituting the demand for locally

Table 5. Suitability of Biofuels in the country excluding sensitive lands

Biodiesel	REGION	NS ESL	NS %	MaS ESL	MaS %	MoS ESL	MoS %	HS ESL	HS %
Jathropha	TIGRAY	2,849,767.88	4.57	946,652.00	5.86	1,081,928.00	3.98	732,040	10.28
	AMHARA	11,948,395.92	19.15	1,143,680.00	7.08	1,427,948.00	5.25	822,692	11.56
	BENISHANGUL-G	3,642,032.36	5.84	43,012.00	0.27	399,308.00	1.47	783,636	11.01
	OROMIA	25,968,233.44	41.62	1,381,928.00	8.56	5,397,800.00	19.84	2,778,992	39.03
	DIRE DAWA	49,017.81	0.08	56	0	14,356.00	0.05	87,336	1.23
	HARARI	34,647.41	0.06	288	0	4,088.00	0.02	416	0.01
	SNNP	9,151,283.47	14.67	587,384.00	3.64	1,095,436.00	4.03	816,996	11.48
	GAMBELLA	1,401,407.50	2.25	690,784.00	4.28	430,904.00	1.58	30,304	0.43
	Afar	2,308,951.27	3.7	2,955,500.00	18.3	3,433,564.00	12.62	639,728	8.99
	SOMALI	4,987,542.99	7.99	8,396,076.00	51.99	13,923,156.00	51.17	427,464	6
	ADDIS ABEBA	49,273.92	0.08	3,364.00	0.02	0	0	0	0
Total		**62,390,553.7**	**100**	**16,148,724.0**	**100**	**27208488**	**100**	**7,119,604.00**	**100**
	REGION	**ESL**	**%**	**ESL**	**%**	**ESL**	**%**	**ESL**	**%**
Castor	TIGRAY	2841133.143	4.54	455714	3.37	1147886	4.35	1,164,981.00	11.17
	AMHARA	11885351.7	19.00	296289	2.19	1572615	5.96	1,588,812.00	15.23
	BENISHANGUL-G	3642335.241	5.82	1262	0.01	233192	0.88	991,346.00	9.50
	OROMIA	25951663.35	41.48	987403	7.31	4891256	18.55	3,697,822.00	35.45
	DIRE DAWA	48988.27993	0.08	0	0.00	9104	0.03	92,650.00	0.89
	HARARI	34621.15919	0.06	8	0.00	2408	0.01	2,379.00	0.02
	SNNP	9148627.31	14.62	367015	2.72	705506	2.68	1,429,886.00	13.71
	GAMBELLA	1401344.545	2.24	598187	4.43	428072	1.62	125,574.00	1.20
	Afar	2449119.851	3.91	2799751	20.73	3445712	13.07	642,924.00	6.16
	SOMALI	5112691.99	8.17	7998665	59.22	13928320	52.83	694,172.00	6.66
	ADDIS ABEBA	49218.39398	0.08	2402	0.02	962	0.00	0.00	0.00
Total		62565094.97	100.00	13506696	100.00	26365033	100.00	10,430,546.00	100.00

Biodiesel	REGION	NS ESL	NS %	MaS ESL	MaS %	MoS ESL	MoS %	HS ESL	HS %
Croton	TIGRAY	2,838,774.32	4.56	314,680.00	0.92	1,135,004.00	13.24	1,321,544.00	17.2
	AMHARA	11,885,386.33	19.08	561,192.00	1.64	819,208.00	9.56	2,076,732.00	27.03
	BENISHANGUL-G	3,643,027.89	5.85	181,760.00	0.53	853,716.00	9.96	189,184.00	2.46
	OROMIA	25,946,505.62	41.65	4,367,516.00	12.73	2,234,468.00	26.07	2,977,768.00	38.76
	DIRE DAWA	49,158.34	0.08	8,264.00	0.02	65,512.00	0.76	27,784.00	0.36
	HARARI	34,563.71	0.06	0	0	88	0	4,744.00	0.06
	SNNP	9,149,306.69	14.69	824,056.00	2.4	1,084,092.00	12.65	591,760.00	7.7
	GAMBELLA	1,401,941.23	2.25	901,252.00	2.63	248,484.00	2.9	576	0.01
	Afar	2,312,114.94	3.71	6,304,504.00	18.37	693,404.00	8.09	30,272.00	0.39
	SOMALI	4,990,872.53	8.01	20,845,092.00	60.75	1,437,544.00	16.77	462,932.00	6.03
	ADDIS ABEBA	49,190.36	0.08	2,408.00	0.01	984	0.01	4	0
Total		**62,300,841.97**	**100**	**34,310,724.00**	**100**	**8,572,504.00**	**100**	**7,683,300.00**	**100**
	REGION	**ESL**	**%**	**ESL**	**%**	**ESL**	**%**	**ESL**	**%**
Cassava	TIGRAY	2,838,774.32	4.56	441,380.00	3.15	900,308.00	3.59	1,429,540.00	12.46
	AMHARA	11,885,386.31	19.08	553,300.00	3.95	896,968.00	3.58	2,006,864.00	17.49
	BENISHANGUL-G	3,643,027.88	5.85	1,172.00	0.01	223,220.00	0.89	1,000,268.00	8.72
	OROMIA	25,946,505.56	41.65	1,011,700.00	7.22	4,659,620.00	18.58	3,908,432.00	34.07
	DIRE DAWA	49,158.34	0.08	0	0	8,408.00	0.03	93,152.00	0.81
	HARARI	34,563.71	0.06	0	0	1,112.00	0	3,720.00	0.03

Table 5. Contd.

	SNNP	9,149,306.67	14.69	348,184.00	2.48	660,244.00	2.63	1,491,480.00	13
	GAMBELLA	1,401,941.23	2.25	598,072.00	4.27	427,556.00	1.7	124,684.00	1.09
	Afar	2,312,411.07	3.71	2,935,980.00	20.95	3,445,280.00	13.74	646,624.00	5.64
	SOMALI	4,990,872.52	8.01	8,120,652.00	57.95	13,856,936.00	55.25	767,980.00	6.69
	ADDIS ABEBA	49,190.36	0.08	3,372.00	0.02	24	0	0	0
Total		**62,301,137.97**	**100**	**14,013,812.00**	**100**	**25,079,676.00**	**100**	**11,472,744.00**	**100**

Biodiesel	**REGION**	**NS**		**MaS**		**MoS**		**HS**	
		ESL	**%**	**ESL**	**%**	**ESL**	**%**	**ESL**	**%**
Cotton Seed	TIGRAY	3,050,830.16	4.84	908,592.00	2.61	1,475,292.00	11.13	172,872.00	10.13
	AMHARA	11,914,747.24	18.9	1,155,928.00	3.32	1,932,220.00	14.58	324,020.00	18.99
	BENISHANGUL-G	3,638,283.75	5.77	28,432.00	0.08	1,051,648.00	7.93	144,776.00	8.49
	OROMIA	25,923,665.89	41.12	4,774,860.00	13.7	4,244,716.00	32.02	548,492.00	32.15
	DIRE DAWA	49,092.01	0.08	8,420.00	0.02	93,140.00	0.7	0	0
	HARARI	34,517.07	0.05	1,044.00	0	3,788.00	0.03	0	0
	SNNP	9,192,986.20	14.58	769,300.00	2.21	1,594,160.00	12.03	132,368.00	7.76
	GAMBELLA	1,401,052.52	2.22	140,736.00	0.4	946,792.00	7.14	65,660.00	3.85
	Afar	2,808,059.71	4.45	5,757,388.00	16.52	738,168.00	5.57	51,340.00	3.01
	SOMALI	4,986,687.45	7.91	21,308,952.00	61.13	1,175,236.00	8.87	266,588.00	15.63
	ADDIS ABEBA	49,123.98	0.08	3,396.00	0.01	0	0	0	0
Total		**63,049,045.97**	**100**	**34,857,048.00**	**100**	**13,255,160.00**	**100**	**1,706,116.00**	**100**

	REGION	**ESL**	**%**	**ESL**	**%**	**ESL**	**%**	**ESL**	**%**
Sweet Sorghum	TIGRAY	2,835,895.48	4.55	12,524.00	1.98	61,752.00	0.68	2,697,576.00	6.59
	AMHARA	11,866,331.74	19.05	143,352.00	22.67	166,404.00	1.84	3,150,740.00	7.7
	BENISHANGUL-G	3,638,243.65	5.84	0	0	7,444.00	0.08	1,217,412.00	2.98
	OROMIA	25,911,311.17	41.6	12,284.00	1.94	121,848.00	1.35	9,446,016.00	23.09
	DIRE DAWA	49,091.47	0.08	0	0	0	0	101,560.00	0.25
	HARARI	34,516.69	0.06	0	0	0	0	4,832.00	0.01
	SNNP	9,183,577.34	14.75	2,912.00	0.46	59,436.00	0.66	2,442,796.00	5.97
	GAMBELLA	1,401,037.08	2.25	0	0	5,996.00	0.07	1,147,192.00	2.8
	Afar	2,326,677.41	3.74	461,156.00	72.92	1,365,604.00	15.1	5,201,924.00	12.72
	SOMALI	4,986,632.50	8.01	0	0	7,255,772.00	80.22	15,495,004.00	37.88
	ADDIS ABEBA	49,123.44	0.08	176	0.03	792	0.01	2,428.00	0.01
Total		**62,282,437.97**	**100**	**632,404.00**	**100**	**9,045,048.00**	**100**	**40,907,480.00**	**100**

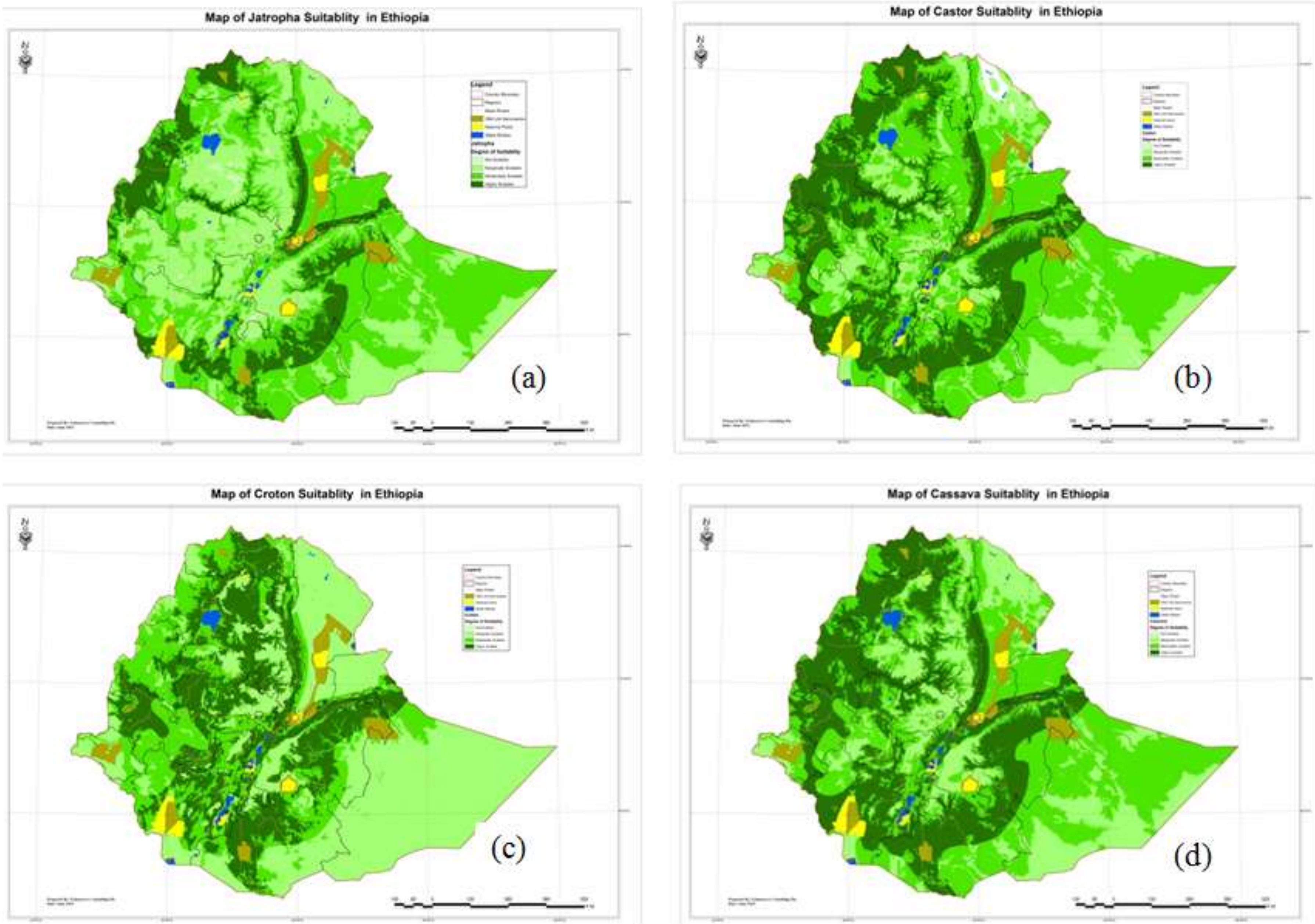
produced fuels such as biofuel (MoME, 2007).

Based on the suitability analysis of the biofuel feedstock considered, the country has huge potential for generating biofuel energy. With an estimated average yield of feedstock per hectare, the country can produce a total of 355.44 and 225.09 billion liters of biodiesels and bioethanols on HS lands alone, respectively. This is equivalent to 53 billion USD. The amount of average production per hectare and prices of the selected biodiesel and bioethanol feedstock's are presented in Table 5. The amount of earning from biofuel can also increase by planting on MoS and MaS area as well as planting the margins of croplands; the biofuels serving as fences. Overall, the production would count towards reducing the amount of fuel the country imports. It also promotes the CRGE strategies of the country without affecting food security.

As the country is also striving for creating conducive environment for local and international investors, it would be a source of foreign currency through direct foreign investment in addition to playing a role in creating job opportunities for the local people.

Conclusion

Ethiopia has a huge potential for biofuel development. Given the country's conducive agro-ecology, availability of ample suitable sites and cheap labor force for biofuel production, part of the fuel energy needs of the country


Map of Jatropha Suitablity in Ethiopia
(a)
Map of Castor Suitablity in Ethiopia
(b)
Map of Croton Suitablity in Ethiopia
(c)
Map of Cassava Suitablity in Ethiopia
(d)

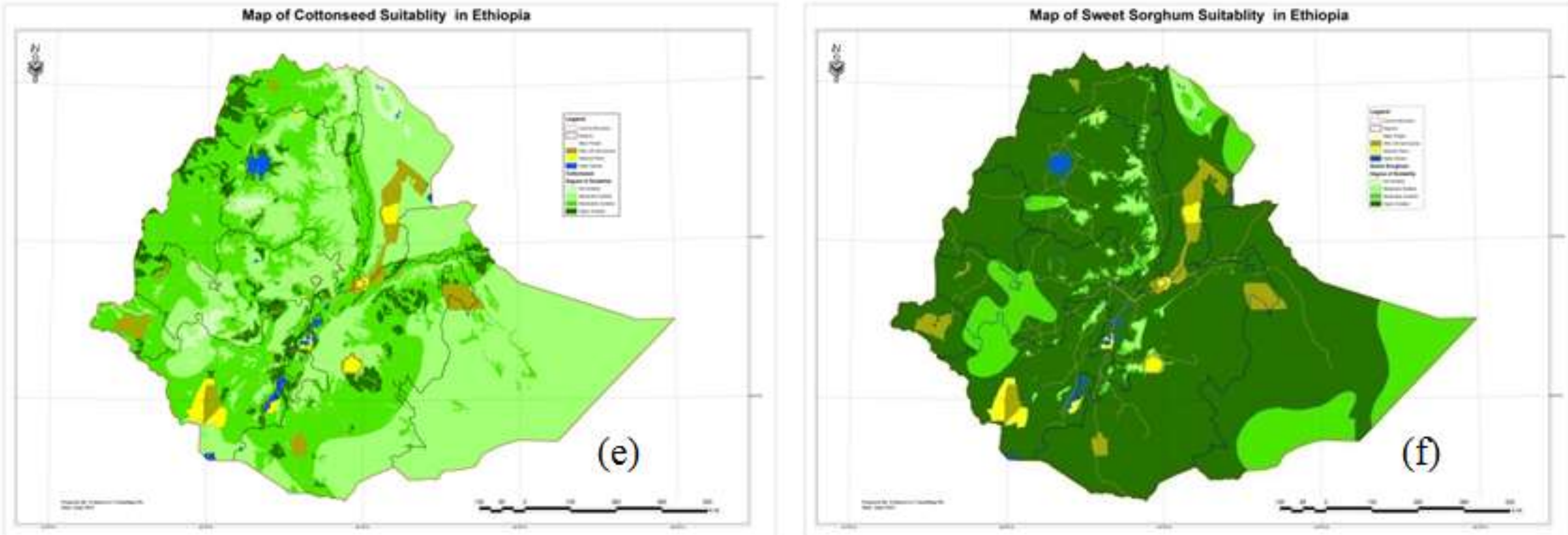
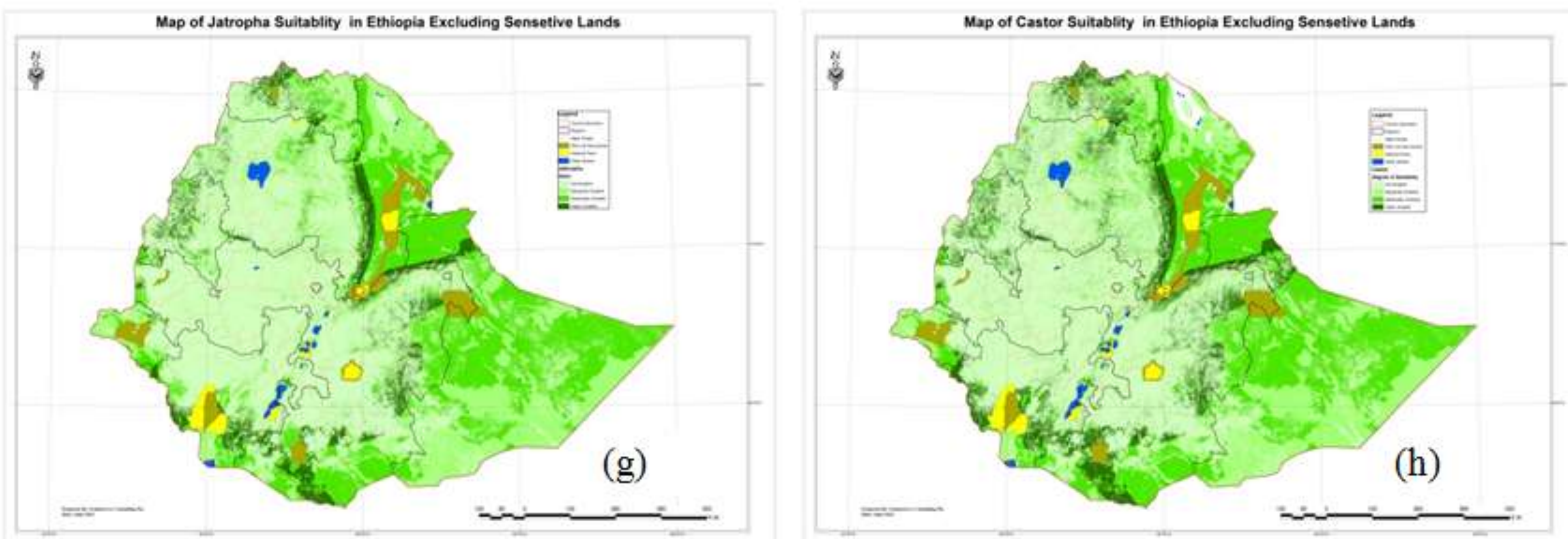


Figure 4. Overall suitability of biofuels: Jatropha (a), Castor (b), Croton (c), Cassava (d),Cottonseed(e) and Sweet Sorghum (f)



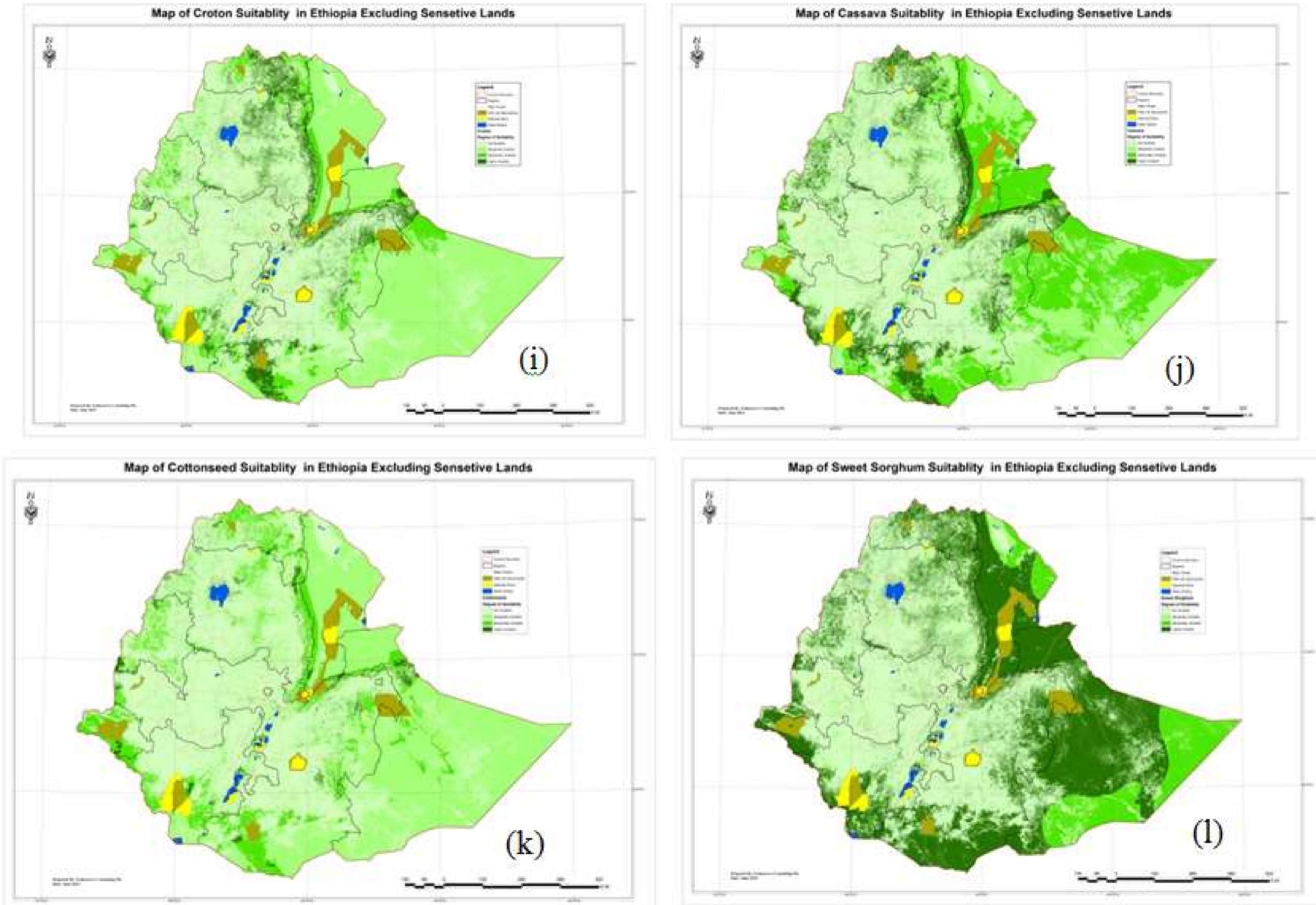


Figure 5. Suitability of biofuels excluding sensitive lands : Jathropha (g), Castor (h), Croton (i), Cassava (j),Cottonseed(k) and Sweet Sorghum (l)

can be satisfied by domestic biofuel production in addition to its potential for export earnings.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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