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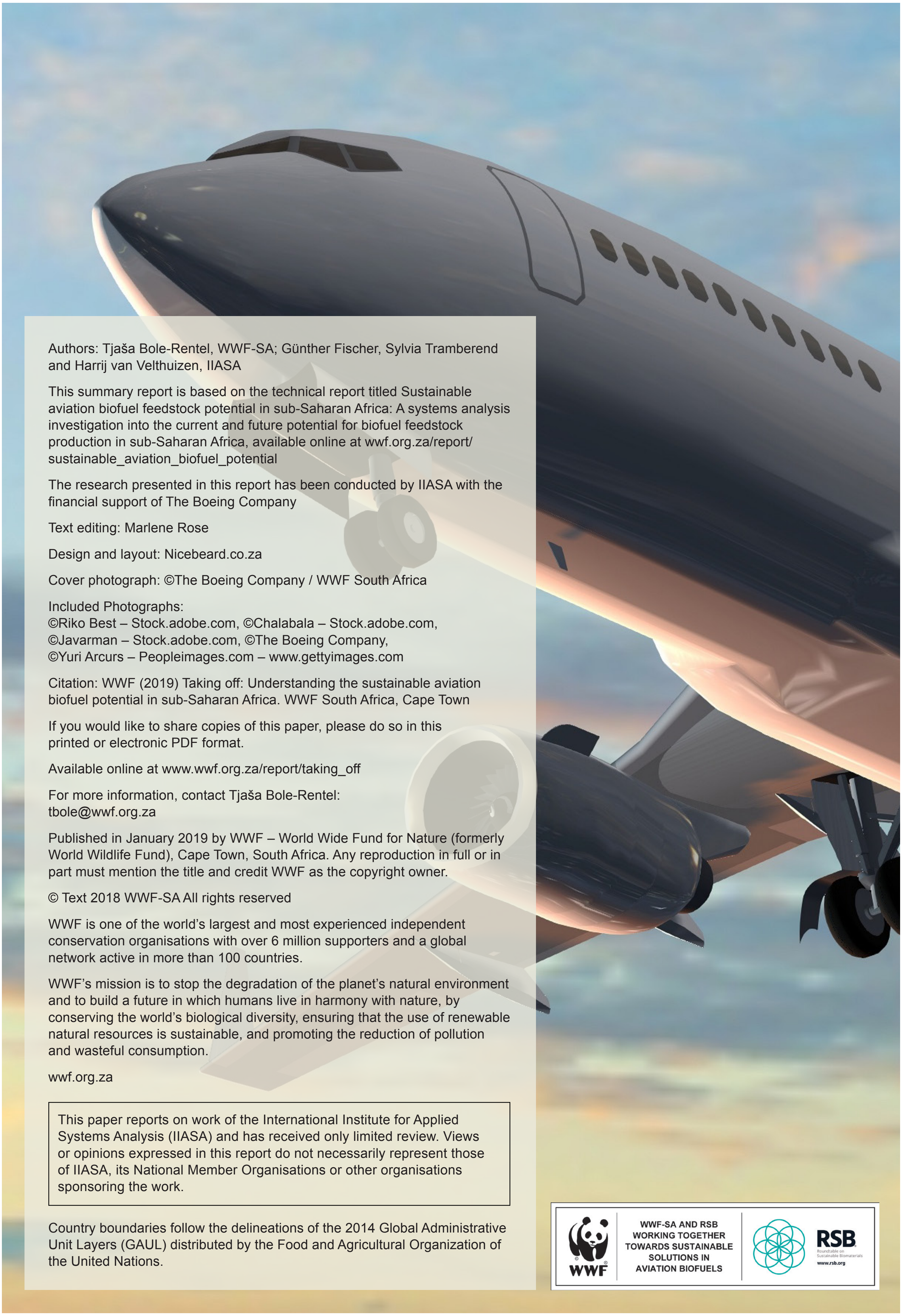
Taking off:

Understanding the sustainable aviation biofuel potential in sub-Saharan Africa

A systems analysis investigation into the current and future potential for sustainable biofuel feedstock production in the sub-Saharan Africa region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Authors: Tjaša Bole-Rentel, WWF-SA; Günther Fischer, Sylvia Tramberend and Harrij van Velthuizen, IIASA

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For more information, contact Tjaša Bole-Rentel:
tbole@wwf.org.za

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Country boundaries follow the delineations of the 2014 Global Administrative Unit Layers (GAUL) distributed by the Food and Agricultural Organization of the United Nations.

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RSB
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ABBREVIATIONS AND ACRONYMS

CAEP	Committee on Aviation Environment Protection
COP21	Conference of the Parties 21
CNG2020	Carbon-Neutral Growth 2020 goal
DRC	Democratic Republic of the Congo
DW	Dry weight
ENV	Environment
FAO	Food and Agriculture Organization
FOR	Forest
GAEZ	Global Agro-Ecological Zones
GCM	General circulation model
GDP	Gross domestic product
GHG	Greenhouse gas
GMO	Genetically modified organisms
ICAO	International Civil Aviation Organization
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
LCA	Life-cycle assessment
MJ	Megajoule
mt	Million tonnes
PJ	Petajoule
ppm	Parts per million
RCP	Representative Concentration Pathways
RSB	Roundtable on Sustainable Biomaterials
SAF	Sustainable aviation fuels
SSA	Sub-Saharan Africa
SSP	Shared Socio-economic Pathways
TJ	Terajoule
UN	United Nations
WFS	World Food System
WWF	World Wide Fund for Nature

INTRODUCTION

The Paris Agreement (UN, 2015b) at COP21 in 2015 brought the global community together in its commitment to limit global warming to a 2 °C temperature increase, with the ambition of a limit of 1.5 °C.

The need to reduce emissions from aviation

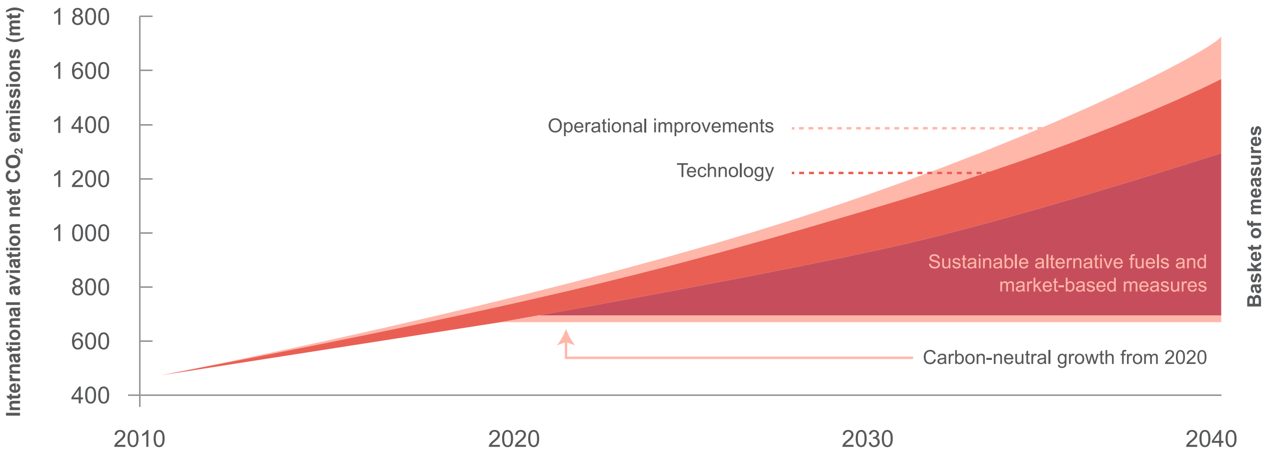
To achieve the goal of 1.5 °C warming, rapid decarbonisation of all economic sectors is required, including those not covered by the Paris Agreement. Aviation is a case in point.

Currently, the aviation sector contributes between 2% and 2.5% of global CO2 emissions (IPCC, 1999; IPCC, 2007; Lee et al., 2009). Adding non-CO2 emissions approximately doubles the sector's contribution to global warming (Lee et al., 2009). Compared to major emitting sectors, these figures may not seem very high. However, the fast growth in air traffic and the related increase in jet fuel consumption means that by 2050 global aviation could account for over 22% of all CO2 emissions (Cames et al., 2015).

To mitigate the growing impact on climate, individual airlines, industry groupings, countries and international organisations have started to put various targets and programmes in place to reduce aviation emissions. To this end, the United Nations (UN) body governing international aviation, the International Civil Aviation Organization (ICAO) has adopted two aspirational goals for the sector — a 2% annual fuel efficiency improvement through 2050, and carbon-neutral growth from 2020 onwards (known as the CNG2020 goal).

It is already clear that the technical and operational advances available today will not be able to keep pace with the fast growth in air traffic. The sector is therefore placing much hope on a combination of alternative fuels and market-based measures (such as carbon offsets) to mitigate growing emissions and close the sector's CO2 gap, as shown in Figure 1.

Figure 1: Contributions of measures for reducing the net CO2 emissions of international aviation



Source: International Civil Aviation Organization (ICAO, 2016)

Box 1: Fair share of emission reductions in aviation

It is worth noting that the aviation emissions trajectory proposed by ICAO does not represent an adequate contribution from the sector to limit global warming to 2 °C. To achieve this target, the international aviation share of CO_2 emissions should remain constant at today's levels, even as the global economy undergoes deep decarbonisation. This translates into a reduction of emissions from international aviation of between 41% and 96% by 2050, compared to 2005 emissions, depending on the point in time at which the sector emissions start declining (Cames et al., 2015).

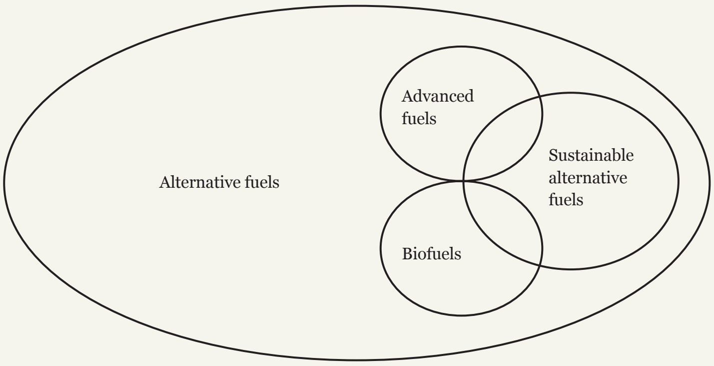
The role of aviation biofuels as a potential mitigation measure

As momentum is building in the aviation sector to address aircraft emissions, biomass-based fuels are once again in the spotlight. Although airlines looking to reduce their carbon footprints could create a substantial demand pull, this comes with sustainability risks. Sustainable aviation fuels (SAF) are no longer synonymous with biofuels because of recent ground-breaking innovation in alternative liquid-fuel technology, yet the expectation is that, in the short to medium term, much of these fuels will be bio-based.

Box 2: Unpacking sustainable alternative aviation fuels

Sustainable alternative fuels are low-carbon fuel alternatives for transportation. These fuels can be refined to comply either with aviation fuel requirements (in which case they are always drop-in fuels blended with conventional aviation fuel) or ground or maritime transportation requirements (in which case they can be used as a blend, or even neat). These non-petroleum-based fuels are generally bio-based (those are referred to as 'biofuels') or produced from waste, residues and end-of-life products (usually referred to as 'advanced fuels').

While many alternative fuels use the language of sustainability, 'alternative fuel' and 'sustainable fuel' cannot always be used as synonyms. Some – especially those based on edible or even non-edible crops – risk having negative social and environmental impacts. They could affect food security when arable land is used for biofuel feedstock production, cause environmental degradation from deforestation and unsustainable soil and water use, result in increased emissions, and many more. For this reason it is crucial that all future aviation biofuel production should be truly sustainable and secured by robust sustainability certification.



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In this study, we use the terms ‘biofuel’ and ‘aviation biofuel’ interchangeably. In principle, the feedstock potential that we estimate could also be used to produce biofuel for land transportation or maritime fuels, although the limited decarbonisation options for aviation compared to land transportation provide grounds for prioritising the use of biomass as a limited resource in aviation.

There are two key questions to ask about the way biofuels can help the aviation sector achieve its goal of carbon-neutral growth by 2020 and possibly contribute to greater emissions reductions in the longer term:

1. How much can sustainably produced aviation biofuels contribute towards fuel supply for the sector?
2. What emission reductions could be achieved by replacing conventional fossil-based jet fuel with aviation biofuels?

All future aviation biofuel production should be subject to robust sustainability certification.

Various estimates already exist. ICAO’s Committee on Aviation Environment Protection (CAEP) estimates that from 2040, up to 100% of the international aviation fuel demand (that is, the majority of total global aviation fuel demand) could be met by biofuels. These figures are based on a number of very optimistic assumptions, like complete fleet renewal with aircraft that can use pure biofuels, massive capital investments in replacing fuel storage, blending and distribution infrastructure that can handle pure biofuels, and high availability of biomass for the production of aviation biofuel.

This is in turn dependent on various other factors, such as the realisation of the highest assumed increases in agricultural productivity, the highest availability of land for biofuel feedstock cultivation, the highest residue removal rates, the highest conversion efficiency improvements, the largest reductions in GHG emissions of utilities, and a strong market or policy emphasis on bioenergy in general and alternative aviation fuel in particular.

It also implies that a large share of globally available bioenergy resources would be devoted to producing aviation fuel, as opposed to other uses (ICAO, 2016).

Other estimates, especially those that consider the price differential between conventional fuel and aviation biofuel, are much less optimistic. There are similar uncertainties about the level of emission savings that can be achieved by aviation biofuels. Many studies have shown the wide ranges of life-cycle emissions for various biofuels, even when they follow the same production process. These ranges depend on many factors, among other things land use prior to biofuel feedstock cultivation, farming practices, yields, logistics, processing efficiencies, collection and distribution distances.

It is therefore neither possible nor advisable to generalise the emissions reduction potential of biofuels, including those used in aviation. Rather, every single supply chain should be subject to a rigorous life-cycle assessment process with adequate system boundaries to determine its value in delivering real, significant and measurable emissions reductions.

Study aim

The aim of this study was to provide a realistic assessment of the current and future biofuel production potential of countries in sub-Saharan Africa. This assessment has been carried out with FAO/IIASA Agro-ecological zones models using the latest available spatial environmental data and feedstock requirement information and meets strict sustainability criteria, including the ability of biofuels to significantly reduce greenhouse gas (GHG) emissions. The sustainability constraints included in the analysis are based on the Roundtable for Sustainable Biomaterials (RSB) criteria, which are considered best-in-class in terms of sustainability standards for bioenergy developments (WWF, 2013).

Biomass is a limited resource and the sustainability of its large-scale supply depends on the resources available for its production. Sustainability must be considered in the broader context of demand for food and water, the need to safeguard natural environments and protected areas, and the competing biomass demand for power generation and transport fuels in other sectors (road and shipping).

In addition, Africa, and particularly sub-Saharan Africa (SSA), is seen as one of the major expansion areas for the production of biofuel feedstock. To ground these aspirations in reality, the development of biomass for energy needs to take account of agricultural and socio-economic development in sub-Saharan Africa.

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APPROACH

The transition to a low-carbon economy by using biomass as one of the energy sources will intensify the linkage between the agriculture and energy sectors.

Biomass production will increase competition for land and water resources, but may at the same time provide new economic prospects for rural communities. As food, feed and energy markets are increasingly integrated, challenges and opportunities will arise. Moreover, the agricultural production system is embedded in a dynamic socio-economic, environmental and cultural setting. Understanding the key linkages within this setting is important if we want to evaluate the possible consequences and indirect effects of policies that govern these markets.

The biofuel potentials that are estimated by following a systems analysis approach are compatible with long-term food security and environmental integrity.

Systems analysis for studying the agriculture-energy-environment nexus

Increasing biofuel feedstock production in sub-Saharan Africa, while at the same time meeting growing food demand and following strict sustainability principles, faces a high degree of complexity. Integrated systems analysis that adequately considers the spatial and inter-temporal linkages of the whole system, while analysing its individual components, provides a suitable analytical framework to address complex systems. In this instance the 'system' under analysis is the agriculture-energy-environment nexus, while food and biofuel feedstock production are its individual, but interdependent, components. The biofuel potentials that are estimated by following such a systems analysis approach are compatible with long-term food security and environmental integrity.

Following the systems analysis approach, the modelling framework employed in this study consists of six main elements:

1. **A storyline and quantified macro-drivers of development.** For this purpose, we chose the widely used Shared Socio-economic Pathways (SSPs), which include projections of demographic changes and economic growth in each country globally. The SSP narratives also include assumptions on important elements of the international setting, such as trade liberalisation, technological progress and the priorities of land-use regulation.
2. **A GHG concentration pathway (measured in CO2 equivalents).** This is associated with the chosen development scenario,[1] which is used to define applicable future climate scenarios. Here we relied on the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathways (RCPs) that are widely used to model the possible climate effects of different CO2 concentrations.

Box 3: What are Representative Concentration Pathways?[2]

RCPs are four GHG concentration (not emissions) trajectories adopted by the IPCC.

The pathways are used for climate modelling and research. They describe four climate futures, all of which are considered possible depending on how much GHG is emitted in future. The four RCPs are: RCP2.6, RCP4.5, RCP6 and RCP8.5.

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[1] For a basic overview of the Scenario Matrix architecture that combines Shared Socio-economic Pathways with anthropogenic forcing of the climate system, see unfccc.int/sites/default/files/part1_iiasa_rogelj_ssp_poster.pdf

[2] For more information on the Representative Concentration Pathways, see for example sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html

3. **The Global Agro-Ecological Zones method (GAEZ).** This methodology takes a climate scenario as input and estimates the likely agronomic impacts of climate change on crop suitability and crop yields on a spatial grid of 5 by 5 arc-minutes latitude/longitude (about 9 by 9 km).

Box 4: Global Agro-Ecological Zones modelling framework (GAEZ)

The core of the analysis of sustainable aviation biofuel feedstock cultivation potentials in sub-Saharan Africa uses the most recent version of the GAEZ modelling framework. This framework describes the agronomically possible upper limit for the production of individual feedstocks under given agro-climatic, soil and terrain conditions for specific levels of agricultural inputs and management conditions.

The GAEZ modelling framework uses 2010 baseline data, including land cover, soil and terrain conditions, protected areas, renewable water resources, population distribution and livestock numbers. It applies climatic conditions for the historical period 1981–2010 and for a selection of future climate simulations using recent IPCC AR5 climate model outputs from five general circulation models (GCMs) and for four different Representative Concentration Pathways.

Climatic data comprises precipitation, temperature, wind speed, sunshine hours and relative humidity. These climate parameters are used to compile agronomically meaningful climate resources inventories, including quantified thermal and moisture regimes in space and time. Geo-referenced global climate, soil, terrain and land-use data are combined into a land resources database. This database is assembled based on global grids, with 5 arc-minute (about 9 by 9 km) and/or 30 arc-second (about 1 by 1 km) resolutions.

Attributes specific to each particular biofuel feedstock contain information such as eco-physiological parameters (e.g. harvest index, maximum leaf area index, maximum rate of photosynthesis), cultivation practices and input requirements, and utilisation of main produce, residues and by-products. The GAEZ procedures are applied separately for rain-fed and irrigated conditions.

Several calculation steps are applied at the grid-cell level to determine potential yields for individual feedstocks. Growth requirements are matched against a detailed set of agro-climatic and edaphic land characteristics derived from the agro-ecological zones land resources database.

For more information on the GAEZ model, see gaez.iiasa.ac.at.

4. **Estimated spatial climate change impacts on crop yields.** These impacts have been aggregated and incorporated into the World Food System model.
5. **The global general equilibrium World Food System (WFS) model.** The WFS model, informed by the development storyline, scenario-specific quantified drivers (population and economic growth) and estimated climate change yield impacts, was used to evaluate global food system scenarios. This model provides a framework for analysing how much food will be produced and consumed in the world, where it will be produced and consumed, and the trade and financial flows related to these activities.[3]

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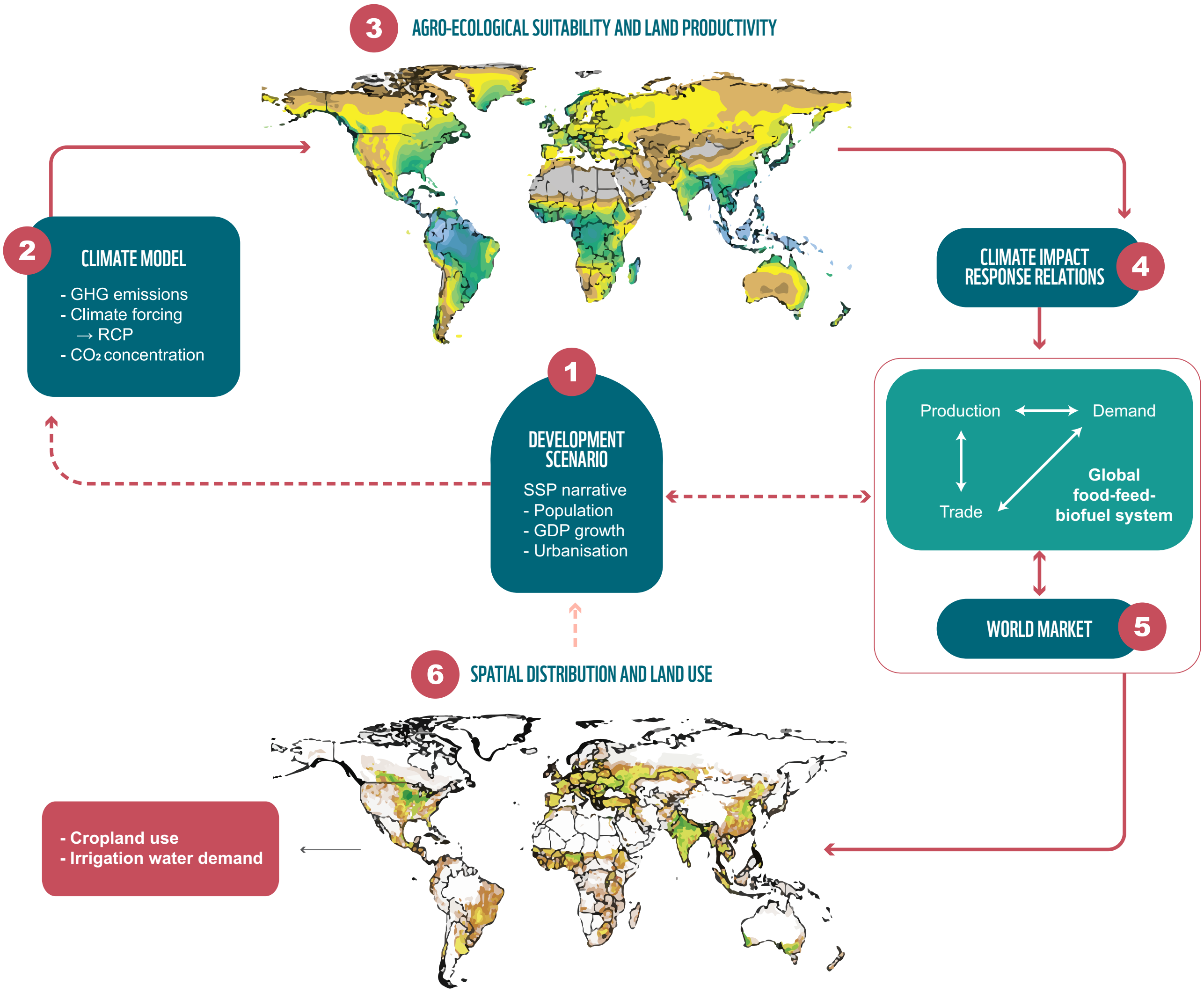
[3] For more information on the World Food System model, see iiasa.ac.at/web/home/research/researchPrograms/EcosystemsServicesandManagement/WFS.en.html

6. **Results of the WFS simulations.** These results were ‘downscaled’ and distributed across the area under investigation, in this case sub-Saharan Africa.

The modelling framework used in this study and its main components are shown in Figure 2.

Figure 2: Ecological-economic modelling framework for future projections applied in this study



Incorporating sustainability principles

The prerequisite for biofuel production in sub-Saharan Africa or elsewhere should be conformity to the highest sustainability criteria. This study relies on the criteria developed by the RSB, which are regarded as best-in-class.

RSB
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Box 5: What is the RSB?

The RSB is an independent and global multi-stakeholder coalition, working to promote the sustainability of biomaterials, including biomass and biofuels, by developing principles and criteria for their sustainable production (RSB, 2016). The RSB principles are general tenets of sustainable production and processing, while the RSB criteria describe the conditions that must be met to achieve these tenets, either immediately (minimum requirements) or over time (progress requirements, to be met over three years).

The 12 RSB principles

PRINCIPLE 1: LEGALITY

Operations follow all applicable laws and regulations.

PRINCIPLE 2: PLANNING, MONITORING AND CONTINUOUS IMPROVEMENT

Sustainable operations are planned, implemented and continuously improved through an open, transparent and consultative impact assessment and management process and an economic viability analysis.

PRINCIPLE 3: GREENHOUSE GAS EMISSIONS

Biofuels contribute to climate change mitigation by significantly reducing life-cycle GHG emissions as compared to fossil fuels.

PRINCIPLE 4: HUMAN AND LABOUR RIGHTS

Operations do not violate human rights or labour rights, and promote decent work and the well-being of workers.

PRINCIPLE 5: RURAL AND SOCIAL DEVELOPMENT

In regions of poverty, operations contribute to the social and economic development of local, rural and indigenous people and communities.

PRINCIPLE 6: LOCAL FOOD SECURITY

Operations ensure the human right to adequate food and improve food security in food-insecure regions.

PRINCIPLE 7: CONSERVATION

Operations avoid negative impacts on biodiversity, ecosystems and conservation values.

PRINCIPLE 8: SOIL

Operations implement practices that seek to reverse soil degradation and/or maintain soil health.

PRINCIPLE 9: WATER

Operations maintain or enhance the quality and quantity of surface and groundwater resources, and respect prior formal or customary water rights.

PRINCIPLE 10: AIR QUALITY

Air pollution must be minimised along the whole supply chain.

PRINCIPLE 11: USE OF TECHNOLOGY, INPUTS AND MANAGEMENT OF WASTE

The use of technologies must seek to maximise production efficiency and social and environmental performance, and minimise the risk of damages to the environment and people.

PRINCIPLE 12: LAND RIGHTS

Operations must respect land rights and land-use rights.

Some of the principles are applicable to and can be assessed only at the project level, for example, Principle 1 on Legality; Principle 2 on Planning, monitoring and continuous improvement; Principle 4 on Human and labour rights; Principle 5 on Rural and social development; and Principle 12 on Land rights.

By contrast, the principles below can be applied at a broad geographic scale and used as constraints to potential biofuel feedstock production. In this study, these principles have been integrated in the biofuel assessment in the following way:

Principle 3: Greenhouse gas emissions

- Any biofuels produced in sub-Saharan Africa must deliver a minimum of 60% GHG emission savings compared to fossil fuels.
- Exclude soils of high organic matter content from biofuel feedstock production.

Principle 6: Local food security

- Reserve cropland needed for current and future food, feed and industrial crop (other than biofuel feedstock) production.
- Safeguard biomass from grassland/savannah required for feeding ruminant livestock.

Principle 7: Conservation

- No deforestation for biofuel feedstock production.
- Safeguard protected areas and ecosystems of high value for biodiversity.

Principle 8: Soil

- Exclude all steep terrain from biofuel feedstock production.
- Biofuel feedstock production follows the principles of conservation agriculture.

Principle 9: Water

- No irrigated biofuel feedstock production in water-scarce areas.
- Because of uncertain data available for the delineation of water-scarce areas, the study considered only rain-fed biofuel feedstock production potential.

Estimating sustainable biofuel feedstock potentials

The estimation of sustainable biofuel feedstock production potentials in this study uses several analysis steps, as summarised in Figure 3. The first six steps in the analysis result in quantifying remaining land that could be considered for biofuel feedstock production once food and environmental sustainability criteria have been taken into account. This is called ‘REMAIN’ land. In the study, a layer of REMAIN land was compiled for base year 2010 and has been dynamically updated to 2050 along with selected scenarios of socio-economic development and climate change, while taking into account projected food demand and related cropland expansion increases.

Figure 3: Overview of assessment steps for the estimation of sustainable biofuel production potential

60%
GHG SAVINGS CRITERION

To be worthwhile, biofuels must deliver a minimum of 60% GHG emission savings compared to fossil fuels.

Steps 1–6 were implemented by defining several land-use-related exclusion layers, where biofuel feedstock production is not considered to take place ('No-go areas'):

- Exclusion layer FOOD
- Exclusion layer FOREST
- Exclusion layer GRAZING LAND
- Exclusion layer ENVIRONMENT

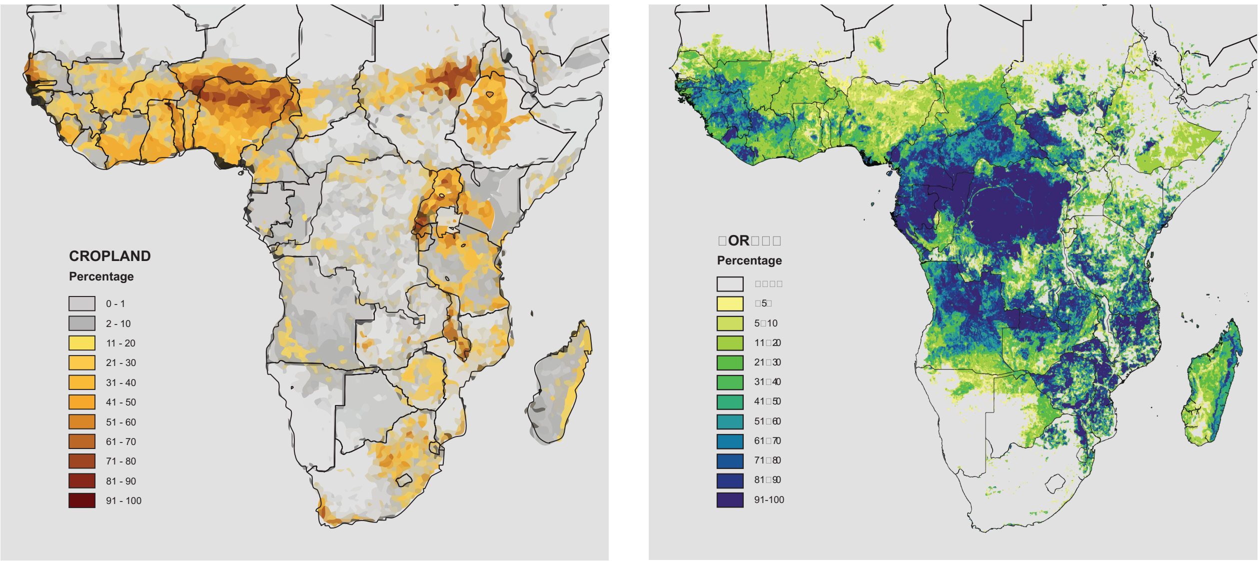
'Exclusion layer FOOD' applies to current and future cropland required for food (including livestock feed crops), according to chosen socio-economic development scenarios (i.e. future food demand estimate based on population growth combined with dietary changes driven by economic growth). In addition, food-security considerations also apply to land used for grazing livestock. For this purpose, we excluded tracts of grassland and shrubland required for feeding livestock ('Exclusion layer GRAZING LAND').

To adhere to *Principle 7: Conservation,* this study has excluded all forested land ('Exclusion layer FOREST'). An additional spatial database was compiled ('Exclusion layer ENVIRONMENT'), delineating legally protected areas and various other areas that currently do not have legal protection status in sub-Saharan Africa but provide key ecosystem services and a high biodiversity value. These include wetlands, key biodiversity areas, strategic water sources and buffer zones around protected areas. Where forests enjoy protection status or carry key biodiversity value, there is an overlap between the 'Exclusion layer FOREST' and 'Exclusion layer ENVIRONMENT'.

Furthermore, we excluded all soils with a high organic matter content. Conversion of these carbon-rich soils was not considered, as the carbon debt of land conversion of such soils would not allow biofuels to meet the minimum 60% GHG savings criterion. In addition, the land-use categories 'bare land' and 'sparsely vegetated land' have severe biophysical limitations for economic feedstock production and were excluded, as were 'built-up land' and 'water'.

Figure 4: Exclusion layers (a) Cropland, (b) Forest, (c) Grazing land, (d) Environment

a) Cropland **b)** Forest



c) Grazing land set aside for livestock **d)** Environment

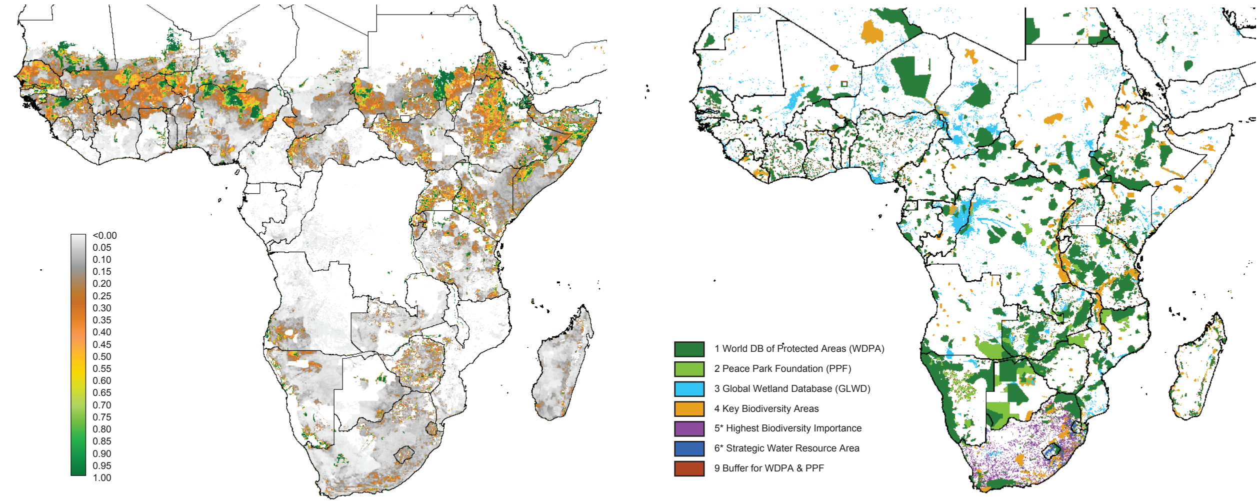
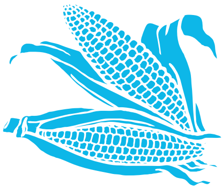


Table 1 shows the biofuel feedstocks assessed in this study grouped by different conversion pathways.

Table 1: Biofuel production chains and biofuel feedstocks

First-generation biofuel production chains	First-generation biofuel production chains	Second-generation biofuel production chains
BIODIESEL	BIOETHANOL	LIGNOCELLULOSIC ETHANOL
• Solaris tobacco • Jatropha • Oil palm • Soybean • Camelina	• Sugarcane • Maize (grain and stover) • Sweet sorghum • Cassava	• Miscanthus • Crop residues



For the study, we assumed that crop residues exceeding 2 t/ha could be used as biofuel feedstock without significantly affecting soil fertility or causing soil erosion.

Agricultural residues like straw, stubble, stalks, cobs, husks and peelings can also contribute biomass for ethanol production via the lignocellulosic conversion route. Crop residues also provide important ecosystem services that are essential to maintain soil fertility and protect against erosion. Technical, environmental and economic factors make it difficult to quantify the availability of these residues for energy purposes. For the calculations in this study, we applied a widely adopted assumption that amounts of crop residues exceeding 2 t/ha could be used as biofuel feedstock without significantly affecting soil fertility or causing soil erosion (Batidzirai et al., 2016).

Greenhouse gas emissions

A primary motivation for biofuel use is that biofuels represent a renewable substitute for fossil fuels and can potentially lower GHG emissions from transport, including air transport. However, in the production of biofuels, emissions arise at every step in the supply chain. These emissions are calculated in life-cycle assessments (LCAs). Life-cycle supply chain GHG emissions arise from the following:

- cultivating biofuel feedstocks
- processing raw material feedstocks into biofuels
- transporting and distributing the fuels (field to wheel).

The results of biofuel LCAs vary significantly depending on various factors or assumptions, in particular:

- the agricultural management approach applied
- the type of energy used in the biofuel conversion process
- the allocation of the GHG burden to different co-products.

Direct land-use change emissions arise when soil carbon and carbon stored in natural vegetation are lost because virgin land is converted to agricultural land for the cultivation of crops.

Additional GHG emissions occur when land covered in natural vegetation is converted to cropland for biofuel feedstock production. These emissions are referred to as ‘direct land-use change’ emissions, and have been added to individual biofuel LCAs to derive a total GHG emission per feedstock-specific biofuel. These direct land-use change emissions vary widely depending on the current land cover, soil type and agricultural management. Direct land-use change emissions can be minimised by using no-till or minimal-till techniques, adding organic input such as manure, and rebuilding biomass carbon stocks by planting perennial plants if agro-climatic conditions are suitable.

Energy crop production may also lead to ‘indirect land-use change’, which often results in additional GHG emissions. The concept of indirect land-use change refers to biofuel feedstocks replacing other crops (food, feed or industrial crops) in one area, with the replaced crop then being produced in another area previously covered in natural vegetation. Thus, when crop displacement by biofuel feedstock cultivation triggers changes in land use (e.g. deforestation) and associated GHG emissions, the net GHG savings provided by biofuels may be diminished or even become negative, meaning they cause even more emissions than the fossil fuel they were meant to replace. The assumptions applied in this study avoid indirect land-use changes because current and future cropland required for food production is reserved up-front (the ‘food first’ principle) and not considered for biofuel feedstock production.

To determine the emission savings, biofuel emissions must be compared to a fossil-fuel reference. The fossil-fuel comparator used in this study is 94 g CO2eq per megajoule.

The fossil-fuel comparator to determine emission savings is 94 g CO2eq per megajoule.

Box 6: Sharing the GHG burden in multi-product crops

Processing biofuel feedstocks and conversion to biofuels often produce significant amounts of useful co-products. Greenhouse gas emissions from the production of crops, including those caused by direct land-use change, should therefore be allocated among the jointly produced products derived from the original feedstock, i.e. the biofuel and the various co-products.

This study applies economic allocation – a common methodology used to partition GHG emissions in the product chain – to biofuels and their co-products. The rationale for economic allocation is that the environmental burdens of a multifunctional process should be allocated in proportion to the market value of each respective product because product demand is considered to be the main driving force in the production system.

Depending on the value of co-products, the GHG burden from direct land-use change allocated to the biofuel varies from 35% (for soybean-based biofuel) to 90% (for oil palm- and sugarcane-based biofuels). Biofuel compliance with RSB criteria is highly sensitive to the GHG burden allocation. The higher the share of the GHG emissions allocated to the biofuel component, the more difficult it is for the biofuel chain to meet the GHG criterion.

Estimating future potential

Sub-Saharan Africa includes regions where population growth rates are among the highest in the world. At the same time, many African countries are also expected to achieve strong economic development. Population growth and increasing wealth will trigger increasing food demand, which will necessitate the expansion of cropland and the narrowing of existing gaps in agricultural productivity.

To estimate future land availability and biofuel potential, we first needed a set of comprehensive assumptions on future socio-economic and climatic conditions. For socio-economic conditions we employed the SSP storylines on possible trajectories for human development and global environmental change during the 21st century. This study analyses two of the five SSP scenarios with basic elements of the narratives mentioned in the section on systems analysis (pp. 10–12).

The scenario *Sustainability – Taking the green road* (SSP1) is the only possible pathway that can most likely meet the recently agreed Sustainable Development Goals (SDGs) (UN, 2015a).

Box 7: Shared Socio-economic Pathways as possible futures

SSP1: Sustainability – Taking the green road

SSP1 is a sustainability scenario where the world shifts gradually, but pervasively, towards a more sustainable path, emphasising more inclusive development that respects perceived environmental boundaries. Increasing evidence of and accounting for the social, cultural and economic costs of environmental degradation and inequality drive this shift. Rapid technological progress makes it possible to reduce the intensity with which we consume natural resources and depend on fossil fuels. Consumption (economic growth) is oriented towards low material growth and lower resource and energy intensity. Low-income countries grow more rapidly, inequality between and within economies falls, and technology spreads. Educational and health investments accelerate the demographic transition,

→

2010-2050

5.8%
SSP1 ANNUAL GDP GROWTH

9.4x
SSP1 INCREASE IN AFRICAN ECONOMY

5%
SSP2 ANNUAL GDP GROWTH

7x
SSP2 INCREASE IN AFRICAN ECONOMY

leading to a relatively low population. The world has an open-trade economy, associated with increasingly effective and persistent cooperation and collaboration of local, national and international organisations and institutions.

These general tendencies in the SSP1 storyline were interpreted as having the following specific agriculture/irrigation-related implications for this study:

- improvement of agricultural productivity owing to advanced technology, while maintaining environmental sustainability
- progressive elimination of barriers and distortions in international agricultural product trade
- progress towards effective land-use regulation, especially to prevent deforestation caused by expanding croplands
- enforcement of legally protected conservation areas
- large improvements in irrigation water-use efficiency, where possible
- reliable water infrastructure and water supply
- substantial improvements in global food security, including low-income countries in sub-Saharan Africa.

SSP2: Middle of the road

SSP2 is a continuation of the current trends scenario, where the world follows a path in which social, economic and technological trends do not shift significantly from historical patterns. Development and income growth proceed unevenly, with some countries making relatively good progress while others don’t. Most economies are politically stable. Global markets function imperfectly. Global and national institutions make slow progress in achieving sustainable development goals. Fossil-fuel dependency decreases slowly. Global population growth is moderate and levels off in the second half of the century because the demographic transition has run its course. However, education investments are not high enough to accelerate the transition to low fertility rates in low-income countries and to significantly slow population growth.

For implementation in this study, the SSP2 narrative translates into assumptions on the continuation of past agricultural growth paths and policies, continued (albeit decreasing over time) protection of national agricultural sectors, and further environmental damages caused by agriculture. It also includes:

- progress of agricultural productivity in developing countries as per the Food and Agriculture Organization (FAO) perspective study ‘World Agriculture: Towards 2030/2050’ (Alexandratos & Bruinsma, 2012)
- increasing per capita consumption of livestock products owing to growing per capita incomes
- slowly reducing barriers and distortions in the international agricultural product trade
- some improvement in water-use efficiency, but limited in low-income countries
- gradual reduction in food insecurity owing to the trickle-down effect of economic development
- persistent food and water insecurity problems in some areas of low-income countries
- no effective measures and protection to prevent deforestation caused by cropland expansion.

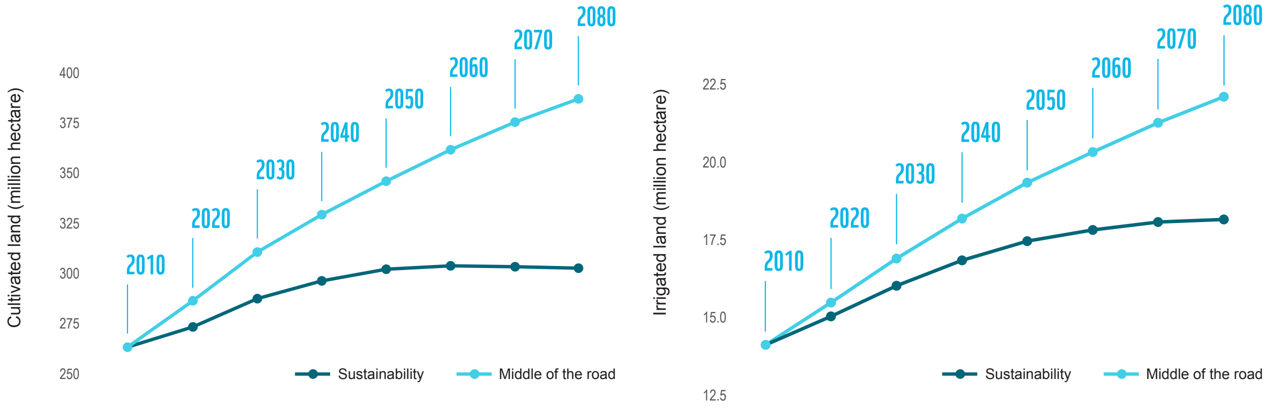
In both SSPs, development in Africa is fairly dramatic. By 2050, population nearly doubles in both scenarios. Fuelled by these rapid demographic changes, both development pathways envisage substantial economic growth, at average annual GDP growth rates of respectively 5.8% (*Sustainability* scenario) and 5% (*Middle of the road* scenario) over the period 2010 to 2050. Thus, relative to 2010, the size of the African economy in 2050 will increase by 9.4 times and 7 times for SSP1 and SSP2 respectively.

Driven by population growth and substantial income gains, food demand in Africa is rapidly increasing. This demand is expected to be met by intensifying current farming activities and by expanding agricultural land into natural habitats, much more so in the *Middle of the road* scenario. The area of cultivated land under irrigation is also expected to increase, as shown in Figure 5.

Figure 5: Evolution of cultivated land and area equipped with irrigation in Africa

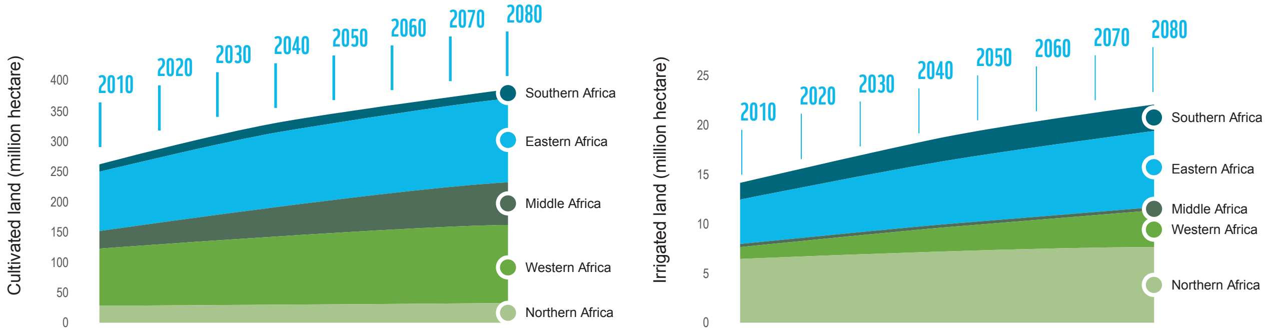
a) Cultivated land

b) Irrigated land



c) Cultivated land (Middle of the road)

d) Irrigated land (Middle of the road)



Source: Own images based on raw data from the SSP database, available at tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about

Each of these development scenarios has been paired with a plausible climate change scenario, represented by one of the RCP scenarios (see Box 3). The more sustainable SSP1 has been paired with RCP2.6, the only climate scenario where global warming is not likely to exceed 1.5 °C. By contrast, SSP2 has been linked to RCP6, which represents a likely increase of 2 °C or more. The two combined scenarios are summarised in Table 2.

Table 2: Scenarios applied in this study

Name of scenario	Socio-economic development assumptions drawn from	Climatic change assumptions drawn from
SC1	SSP1: Sustainability – Taking the green road	RCP2.6
SC2	SSP2: Middle of the road	RCP6

The combination of SSP1 socio-economic development and RCP2.6 climatic changes (scenario SC1 in this study) portrays an open and cooperative world oriented towards sustainability. Greenhouse gas mitigation policies are ambitious and sufficient to meet the Paris Agreement goal of keeping global mean temperatures below 2 °C by 2100.

The second combination, using SSP2 socio-economic drivers and RCP6 GHG concentrations (scenario SC2 in this study) represents a world following the patterns and behaviour of the past and perpetuating business-as-usual trends.

INSIGHTS FROM THE MODELLING

The first step in the assessment was to delineate and quantify the tracts of land potentially available for sustainable biofuel feedstock production.

24.2 mil km^2

TOTAL LAND AREA

2.4 mil km^2

AREA CURRENTLY CULTIVATED

1 mil km^2

AREA REQUIRED AS GRAZING LAND

6.1 mil km^2

AREA UNDER FORESTS

2.9 mil km^2

PROTECTED AND HIGH BIODIVERSITY AREAS

5.5 mil km^2

REMAIN LAND POTENTIALLY AVAILABLE FOR BIOFUEL PRODUCTION

Current availability of land potentially available for biofuel feedstock production and suitability for production of energy crops

Sub-Saharan Africa's total land area amounts to 24.2 million km^2, from which we deducted various tracts of land in order to comply with the RSB principles.

RSB Principle 6: Local food security is stringently applied by reserving all cropland for food security and excluding it from biofuel feedstock production. Currently about 2.4 million km^2 or 10% of the total land area in sub-Saharan Africa is cultivated for crop production. In addition to cropland, about 1 million km^2 of grassland and shrubland is currently required as grazing land for livestock, and is also excluded.

RSB Principle 7: Conservation lists forests (according to the FAO definition) as 'no-conversion' areas. We therefore excluded all sub-Saharan forests from potential biofuel feedstock production areas, amounting to about 6.1 million km^2. The full exclusion of forests is also justifiable under *RSB Principle 3: Greenhouse gas emissions*. If forests are converted to cropland, the GHG debt resulting from these actions will mean that any biofuels produced from feedstock grown on this land will not comply with the minimum GHG emission reduction requirement. We also excluded protected areas and high biodiversity value areas other than forests, which added up to another 2.9 million km^2.

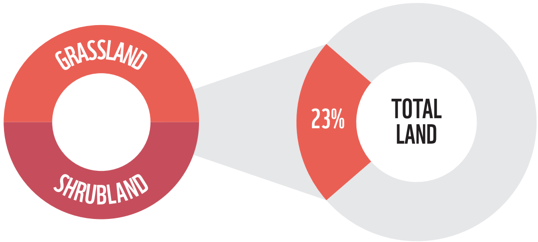
All these areas are designated as 'no-go areas' for energy crop production, and have been excluded from the biofuel feedstock assessment. In addition, we excluded sparsely vegetated and bare land because these areas are not considered viable for commercial rain-fed farming. This left a balance of 5.5 million km^2 of land – almost evenly split between grassland and shrubland – potentially available for biofuel feedstock production. We termed these areas 'REMAIN land' (Table 3, Figure 6).

Table 3: Availability of current REMAIN land

	million km^2
Total land extent (2010)	24.3
Exclusion layer FOOD	-2.4
Exclusion layer GRAZING	-1.0
Exclusion layer FOREST	-6.9
Exclusion layer ENVIRONMENT	-2.9
Exclusion SPARSELY VEGETATED and BARE LAND	-5.1
Built-up areas and water bodies	-0.5
REMAINING LAND CONSIDERED FOR BIOFUEL FEEDSTOCK PRODUCTION	5.5

Source: Own calculations

Figure 6:
Share of REMAIN land relative to total land in sub-Saharan Africa, in 2010



Large tracts of REMAIN land are found in southern Africa and Sudano-Sahelian Africa (about 1.4 million km^2 each) followed by central Africa (1.14 million km^2) and eastern Africa (1 million km^2). In the Gulf of Guinea region, REMAIN land amounts to less than 0.4 million km^2 (Table 4).

Table 4: Extent of REMAIN land by region, in 2010

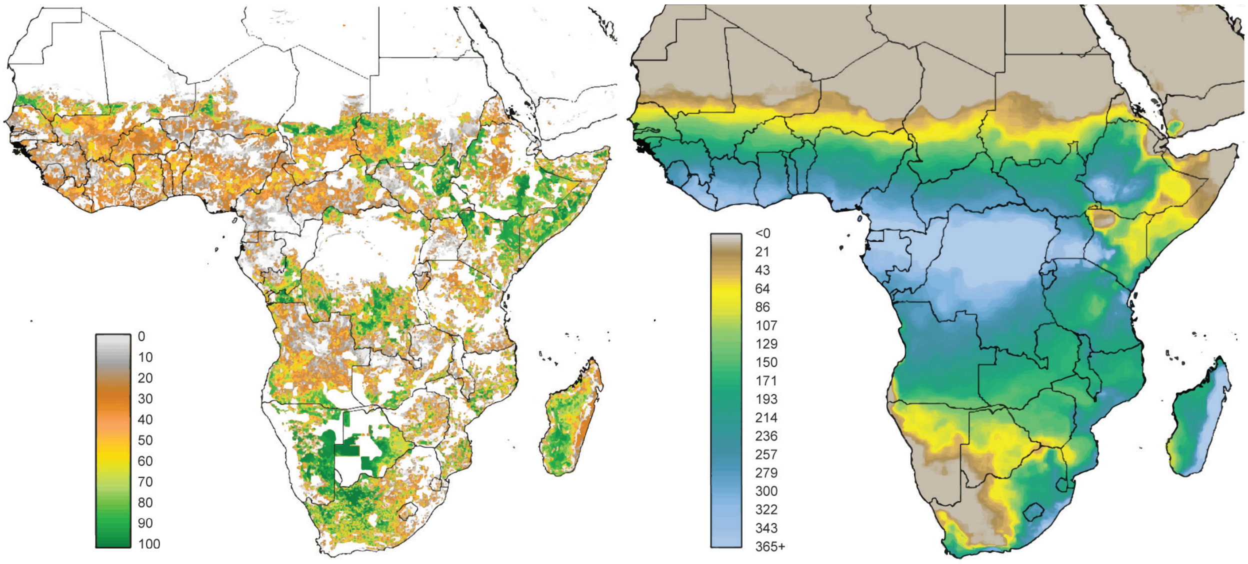
Region	Total land	REMAIN land in 2010	
	'000 km^2	'000 km^2	%
Eastern Africa	3 562	1 042	29
Central Africa	5 329	1 152	22
Southern Africa	4 737	1 431	30
Sudano-Sahelian Africa	8 541	1 493	17
Gulf of Guinea	2 097	386	18
Total sub-Saharan Africa	24 266	5 504	23

Source: Own calculations

In Figure 7, the map on the left shows the distribution and density of REMAIN land across sub-Saharan Africa in 2010. At country level, the extent of REMAIN land varies from less than 10% of total area in smaller countries (Rwanda, Equatorial Guinea, Djibouti, Gambia) or densely populated ones (Rwanda, Gabon) to approximately 40–50% in South Africa, Somalia and Madagascar.

The map on the right shows the estimated number of annual growing period days under current climatic conditions. Combined together, the maps indicate that a high density of REMAIN land usually coincides with limiting climatic conditions, although there are exceptions as in parts of central Africa, Mozambique and South Sudan.

Figure 7: Intensity and spatial distribution of REMAIN land (%) and number of annual growing period days, in 2010



This means that **only a relatively small fraction of REMAIN land can support economically viable biofuel feedstock production because of differences in prevailing agro-climatic, soil and terrain conditions**. These areas are classified as very suitable (VS) (prime) or suitable (S) (good) for specific energy crop production, meaning that crop production in these areas will achieve 60–100% of potential rain-fed yield assuming advanced input/management regimes. Moderately suitable (MS) land where 40–60% of best yields can be achieved is often not economically viable for commercial production, but may become so with high commodity demand and resulting high raw material prices.

Box 8: Suitability classes reported in Global Agro-Ecological Zones (GAEZ)

Acronym	Suitability description	Farm economics
VS	Very suitable land (80–100% of maximum achievable yield in sub-Saharan Africa)	Prime land offering best conditions for economic feedstock production
S	Suitable land (60–80%)	Good land for economic feedstock production
MS	Moderately suitable land (40–60%)	Moderate land with substantial climate and/or soil/terrain constraints requiring high product prices for profitability
mS	Marginally suitable land (20–40%)	Commercial production not viable – land could be used for subsistence production when no other land is available
VmS	Very marginally suitable land (<20%)	Economic production not feasible
NS	Not suitable	Production not possible

24.2 mil km^2

SSA TOTAL LAND AREA

5.5 mil km^2

TOTAL REMAIN LAND

1.9 mil km^2

PRIME AND GOOD REMAIN LAND FOR PRODUCTION OF ENERGY CROPS

0.8 mil km^2

GHG CRITERION-COMPLIANT PRIME AND GOOD REMAIN LAND

The extent of suitable REMAIN land for biofuel feedstock cultivation depends on the particular feedstock that is cultivated. Between only 1% (triticale) and 29% (sweet sorghum) of sub-Saharan Africa's REMAIN land is of prime or good quality for the cultivation of sugar and/or starch-producing crops. About 4.5% of REMAIN land or 0.25 million km^2 – mostly found in the subhumid zone – is of prime or good quality for rain-fed sugarcane cultivation. Areas that are considered 'very suitable' for miscanthus require good rainfall, such as in parts of central and eastern Africa. A large part of Africa is assessed as only moderately suitable or suitable for miscanthus.

Similarly, suitability for oil-producing crops also varies considerably across the region. Solaris tobacco and especially camelina are confined to tropical and subtropical highland areas, whereas oil palm is only suitable for rain-fed cultivation in pockets at tropical forest zone fringes. The maps clearly show that the widest geographical coverage of suitability is achieved by soybeans and jatropha, for which 25% and 17% of REMAIN land is considered suitable or very suitable for rain-fed cultivation respectively. For Solaris tobacco this figure is 7%, for oil palm 1.5% and for camelina only 1%.

However, not all REMAIN land that is at least moderately suitable for the cultivation of energy crops will support the production of biofuels that are compliant with the minimum 60% GHG savings criterion. In fact, **adding the GHG criterion further significantly restricts the areas and feedstock types that can be used to produce RSB-compliant biofuel**. This is mainly owing to emissions from direct land-use change – in other words, emissions that take place when virgin grassland or shrubland is converted to agricultural land for biofuel feedstock cultivation. As a result, most of the annual crops are not a viable proposition on much of the identified REMAIN land. Perennial crops, on the other hand, are able to meet the strict 60% GHG savings criterion more often because part of the carbon that is initially lost through the conversion of grassland or shrubland to agricultural land is restocked in the parts of the crops that are not regularly harvested, and because soil carbon is better protected.

Biofuel production on remain land

Table 5 presents the extent and corresponding biofuel production potential of ‘prime and good quality’ and ‘prime, good quality and moderately suitable’ REMAIN land in sub-Saharan Africa. Of the total 1 910 000 km^2 of REMAIN land that is of prime and good quality for the production of at least one of the feedstocks considered in this study (see Table 1), only about 838 000 km^2 (almost 84 million hectares) of REMAIN land would produce energy crops that could be used to produce biofuels that comply with the GHG savings criterion. This is 44% of all REMAIN land of prime and good quality, or about 15% of total REMAIN land, and is still somewhat more than the land area of Namibia (825 418 km^2), the 15th biggest country in Africa.

Similarly, the total achievable energy yield on prime and good quality land is 18 650 PJ, but less than half of that (7 064 PJ) would be compliant with the required minimum 60% reduction in GHG emissions. If moderately suitable areas are also considered, the land that meets the 60% GHG savings criterion almost doubles to 1 570 000 km^2 (or 29%) of total REMAIN land, as does the compliant energy yield.

TECHNICAL POTENTIAL

The maximum achievable production potential considering REMAIN land availability, current agro-climatic conditions and RSB criteria.

ECONOMIC POTENTIAL

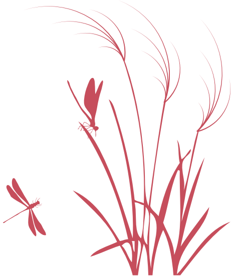
Production potential that is commercially attractive because it offers sufficient returns on investment.

Table 5: Suitability and productivity of prime, good quality and moderately suitable REMAIN land for rain-fed biofuel feedstock production in sub-Saharan Africa, and compliance with 60% GHG savings criterion

REMAIN land	Total area ('000 km^2)	Compliance with 60% GHG savings criterion		Total potential (PJ)	Compliance with 60% GHG savings criterion	
		Area ('000 km^2)	%		Prod. (PJ)	%
Prime and good quality	1 915	838	44	18 650	7 064	38
Prime, good quality and moderately suitable	2 851	1 570	55	24 799	15 510	63

Source: Own calculations

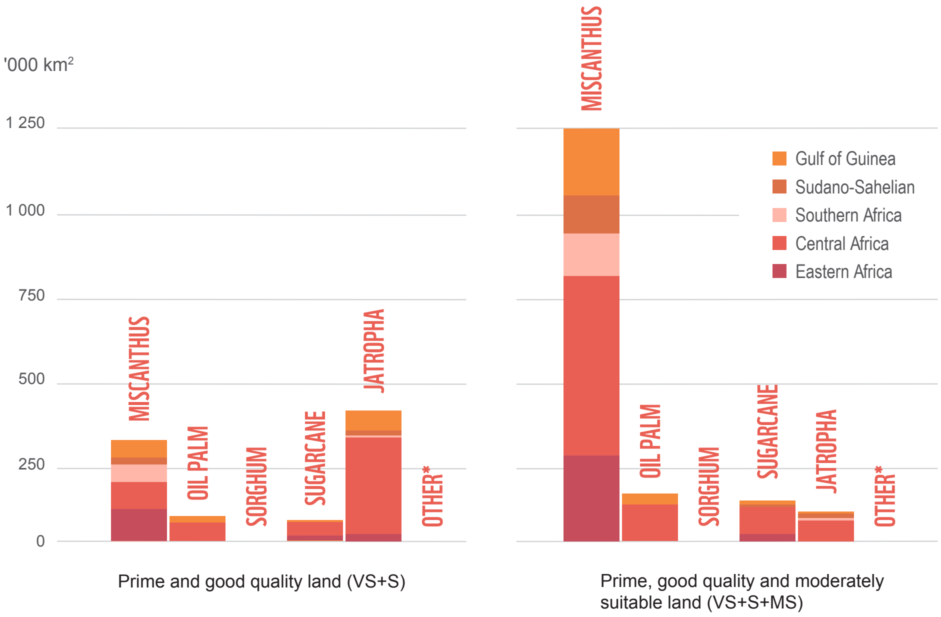
The ‘compliant energy potential’ presented here is essentially the **technical potential of RSB-compliant biofuels in sub-Saharan Africa** and, as expected, compriwbses mostly perennial crops. As shown in Figure 8, if only prime and good quality land were considered for feedstock production, then miscanthus would be planted on about 300 000 km^2 across the whole sub-Saharan African region, and jatropha could be planted on approximately 400 000 km^2, mostly in central Africa. If farming moderately suitable land was viable, then miscanthus could be produced on almost 1.25 million km^2 across the region for the production of the biggest possible quantities of RSB-compliant aviation biofuel. Sugarcane, oil palm and jatropha would be the best option in some parts of central Africa, but on much smaller tracts of land.



Miscanthus emerges as the most promising feedstock by far, contributing about 50% of the total potential if only prime and good quality land is considered, and 75% if moderately suitable land is included. Jatropha and oil palm share second place in terms of RSB-compliant biofuel feedstock potential on prime and good quality REMAIN land, but the potential for jatropha diminishes considerably if tracts of moderately suitable land are also considered. The potential for sugarcane does not change much based on land suitability.

Miscanthus emerges as the most promising feedstock by far.

Figure 8: Geographical distribution of best-performing RSB-compliant feedstocks on REMAIN land under current conditions



* These extents include small amounts of Solaris tobacco that meet the GHG savings criterion in southern Africa.
Source: Own calculations

The total current technical potential for RSB-compliant biofuel in sub-Saharan Africa is in the order of 7 000 PJ, or 165 mt of aviation biofuel (assuming a typical energy content of jet fuel (kerosene) of 42.8 MJ/kg), if energy crops are only produced on prime and good quality land. If the economics of biofuel production are good enough to justify farming on land that is only moderately suitable for the production of energy crops as well, then the technical potential more than doubles to about 15 000 PJ or 330 mt of aviation biofuel.

Table 6: Technical potential for RSB-compliant biofuel on REMAIN land, under current conditions

	Regions	Eastern Africa	Central Africa	Southern Africa	Sudano-Sahelian Africa	Gulf of Guinea	Sub-Saharan Africa TOTAL
		PJ	PJ	PJ	PJ	PJ	PJ
Potential from prime and good quality land	Sugarcane	253	513	0	26	115	907
	Miscanthus	1 188	959	584	291	594	3 645
	Oil palm	38	989	0	0	297	1 294
	Jatropha	84	882	33	36	183	1 217
	Solaris	0	0	1	0	0	1
	TOTAL VS+S	**1 564**	**3 342**	**617**	**353**	**1 188**	**7 064**
Potential from prime, good quality and moderately suitable land	Sugarcane	301	898	0	27	167	1 394
	Miscanthus	2 644	4 923	1 293	1 058	1 990	11 908
	Oil palm	47	1 293	0	0	437	2 023
	Jatropha	11	126	3	30	2	184
	Solaris	0	0	1	0	0	0.3
	TOTAL VS+S+MS	**3 003**	**7 499**	**1 297**	**792**	**2 596**	**15 510**

Source: Own calculations

Sustainable biofuel production in the future

SC1

17% RELATIVE INCREASE IN CROPLAND BY 2050

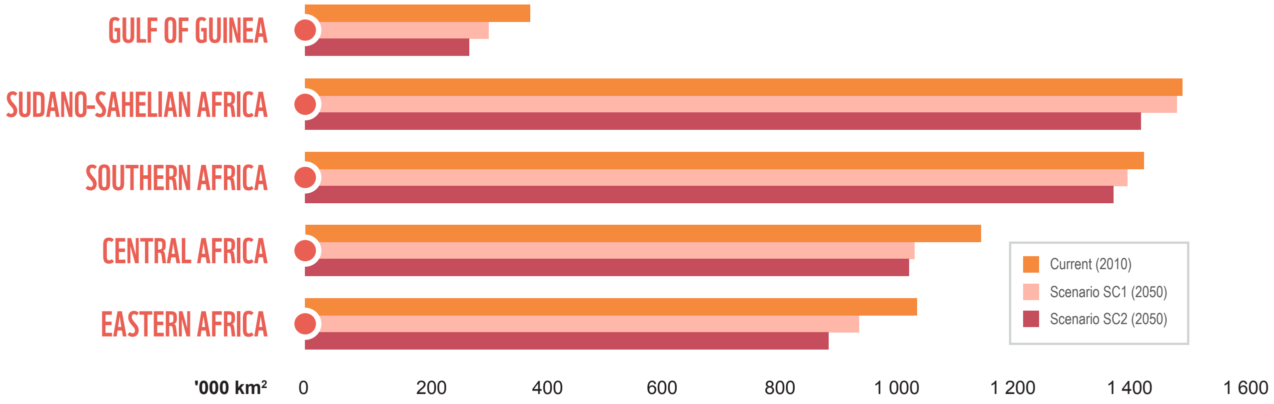
SC2

33% RELATIVE INCREASE IN CROPLAND BY 2050

The general trend in land-use changes in the two development storylines (SSP1 and SSP2; see Box 7) – owing to population growth and the required expansion of agricultural production – is an increase in both cropland and built-up areas. In scenario SC2, where future development is assumed to be less sustainable, cropland for food production and built-up land, respectively, are projected to increase by 792 000 km² and 168 000 km² between 2010 and 2050. Scenario SC1, which assumes a more sustainable development path, achieves a higher crop yield growth than scenario SC2. At the same time, population grows less for SC1 compared to SC2. The demand for expanding cropland is therefore less in scenario SC1 than in scenario SC2, namely 409 000 km², with an additional 126 000 km² required for built-up areas.

Because of land conversions required for additional food production and the expanding built environment, by 2050 the total REMAIN land will be reduced by between 320 000 km² or approximately 6% (scenario SC1) and 501 000 km² or approximately 10% (scenario SC2), as shown in Figure 9. The magnitude of land-use change varies across regions and countries owing to differences in population growth and quality of resource endowments.

Figure 9: Changes to the extent of REMAIN land between 2010 and 2050, by region



Source: Own calculations

Table 7 presents a summary for sub-Saharan Africa, comparing current and future technical potentials for biofuel production for the two scenarios explored in this study. It shows that the future potentials have been reduced significantly. If only prime and good quality land is considered, the projected reduction compared to the current production potential is more than 40%. If moderately suitable areas are also included, the reduction is less pronounced – about 28% in both scenarios. This is the result of a combination of factors:

- a reduction in REMAIN land (of between 6% and 10%)
- the conversion of part of the better quality REMAIN land to cropland for food production
- the impact of climate change on agricultural productivity, which causes some tracts of land currently classified as 'prime' and 'good quality' for the production of energy crops to become only moderately suitable in the future.

The crop most dramatically affected by the combination of the above factors is sugarcane, with its energy yield expected to decline by about 70–80%. Miscanthus and oil palm are also expected to see a significant reduction in their energy yields, more so on prime and good quality land than on moderately suitable land. On the other hand, the yield of some other crops is likely to improve significantly owing to climate change, for example sorghum, jatropha and Solaris tobacco. This is as a result of the specific pattern of projected climate change combined with the CO2 fertilisation effect.

Box 9: The CO2 fertilisation effect

The CO2 fertilisation effect is the direct effect of increased atmospheric CO2 concentration on crop yields, because of an increase in the rate of photosynthesis and the more efficient use of water by plants (Kimball et al., 2002).

Table 7: Current and future production potential of RSB-compliant biofuel on REMAIN land, per feedstock

		Current potential	Future potential – SC1 (2050)		Future potential – SC2 (2050)	
	Climate – CO$_2$	360 ppm	443 ppm		493 ppm	
		PJ	PJ	% change	PJ	% change
Prime and good quality land	Maize	0	0	0	0	0
	Sorghum	0	18	1 800	38	3 800
	Triticale	0	0	0	0	0
	Cassava	0	0	0	0	0
	Sugarcane	907	222	-76	150	-83
	Miscanthus	3 645	1 890	-48	1 963	-46
	Oil palm	1 294	801	-38	920	-29
	Jatropha	17	1 001	5 788	906	5 229
	Soybean	0	0	0	0	0
	Camelina	0	0	0	0	0
	Solaris	1	30	3 000	28	2 700
	TOTAL	**7 064**	**3 962**	**-44**	**4 003**	**-43**
Prime, good and moderately suitable land	Maize	0	0	0	0	0
	Sorghum	0	37	3 700	71	7 100
	Triticale	0	0	0	0	0
	Cassava	0	0	0	0	0
	Sugarcane	1 394	422	-70	306	-78
	Miscanthus	11 908	8 934	-25	8 848	-26
	Oil palm	2 023	1 545	-24	1 754	-13
	Jatropha	184	204	11	150	-18
	Soybean	0	0	0	0	0
	Camelina	0	0	0	0	0
	Solaris	1	28	2 700	30	2 900
	TOTAL	**15 510**	**11 171**	**-28**	**11 159**	**-28**

Source: Own calculations

In terms of changes in the production potential across the sub-Saharan region, Table 8 shows that significant reductions are to be expected across the whole subcontinent. Again, the reductions are most pronounced if only prime and good quality areas are considered.

Table 8: Changes in technical biofuel potential of REMAIN land compliant with the GHG savings criterion, by region

		Current	Future potential – SC1		Future potential – SC2	
	Climate – CO_2 concentration	360 ppm	443 ppm		493 ppm	
Prime and good quality land	Eastern Africa	1 564	872	-44	810	-48
	Central Africa	3 342	2 099	-37	2 236	-33
	Southern Africa	617	329	-47	400	-35
	Sudano-Sahelian Africa	353	262	-26	273	-23
	Gulf of Guinea	1 188	400	-66	285	-76
	TOTAL	7 064	**3 962**	**-44**	**4 003**	**-43**
Prime, good quality and moderately suitable land	Eastern Africa	3 003	1 988	-34	1 843	-39
	Central Africa	7 499	5 513	-26	5 907	-21
	Southern Africa	1 297	922	-29	1 010	-22
	Sudano-Sahelian Africa	1 115	1 018	-9	961	-14
	Gulf of Guinea	2 596	1 731	-33	1 439	-45
	TOTAL	**15 510**	**11 171**	**-28**	**11 159**	**-28**

Source: Own calculations

In summary, the **future biofuels production potential will likely be significantly reduced** as a result of land conversion for food production, changes in land suitability and the impacts of climate change on crop yields. **If only prime and good quality land are considered for feedstock production, the reduction will be over 40%, and if moderately suitable land is included, it will be almost 30%**.

Crop residues from food production

Biofuel need not come from cultivated crops only. Agricultural and other residues and organic waste can be used as lignocellulosic feedstock for second-generation biofuel production pathways. At the same time, some crop residues, especially straw, have alternative uses. They play a role in animal feeding and bedding and a certain proportion needs to be returned to the fields to maintain soil fertility and protect against erosion. Bagasse, the pulpy residue left after extraction of the juice from sugarcane stalks, is often used as fuel in sugar mills.

In sub-Saharan Africa, an estimated 235 mt in dry weight crop residues (stalks and straw) were generated in 2009–2011 as by-products from growing cereals on about 940 000 km^2. More than a third of this was from maize production (37%), followed by sorghum (24%), millet (17%) and rice (14%). Major oil crops and cotton, growing on about 180 000 km^2, generate another 41 mt dry weight of crop residues. Sugarcane harvesting (on 13 000 km^2) produces approximately 4.3 mt of biomass from tops and leaves (currently mostly being burnt at harvest) and another 7.5 mt as bagasse.

As a rule, it is recommended that two tonnes of crop residue per hectare should remain on the fields as cover to reduce soil loss risks (Andrews, 2006; Batidzirai et al., 2016; Papendick & Moldenhauer, 1995) and maintain soil fertility. This rule, combined with the current relatively low crop yields achieved in large parts of sub-Saharan Africa, means that about two-thirds of the total production of crop residues in this region are required for soil protection. This leaves **97 mt of dry weight potentially available for other uses**. Of these, cereal residues are the most obvious candidates for biofuel feedstock, with 75 mt of cereal residue potentially generating up to 480 PJ of biofuel. **This could add around 7% to the biofuel potential from REMAIN land, via the lignocellulosic conversion route**. By comparison, the estimated potential from mischanthus, which would also be processed to fuel via the lignocellulosic conversion route, is about 10 times larger. If all residues could be converted to biofuel, they would add around 9% to the potential energy supply from dedicated crops.

Table 9: Current availability of crop residues from cereals, oil crops and sugarcane production, allowing 2 t/ha to remain in fields

	Eastern Africa	Central Africa	Southern Africa	Sudano-Sahelian Africa	Gulf of Guinea	Sub-Saharan Africa
'000 tonnes dry weight						
Cereals	23 736	2 553	16 275	9 762	23 397	75 724
Oil crops	1 489	727	2 570	2 995	4 040	11 822
Sugarcane	3 024	529	4 369	1 271	444	9 638
TOTAL	**28 249**	**3 809**	**23 215**	**14 028**	**27 882**	**97 183**

Source: Own calculations based on FAO-reported harvested areas and production for 2009–2011

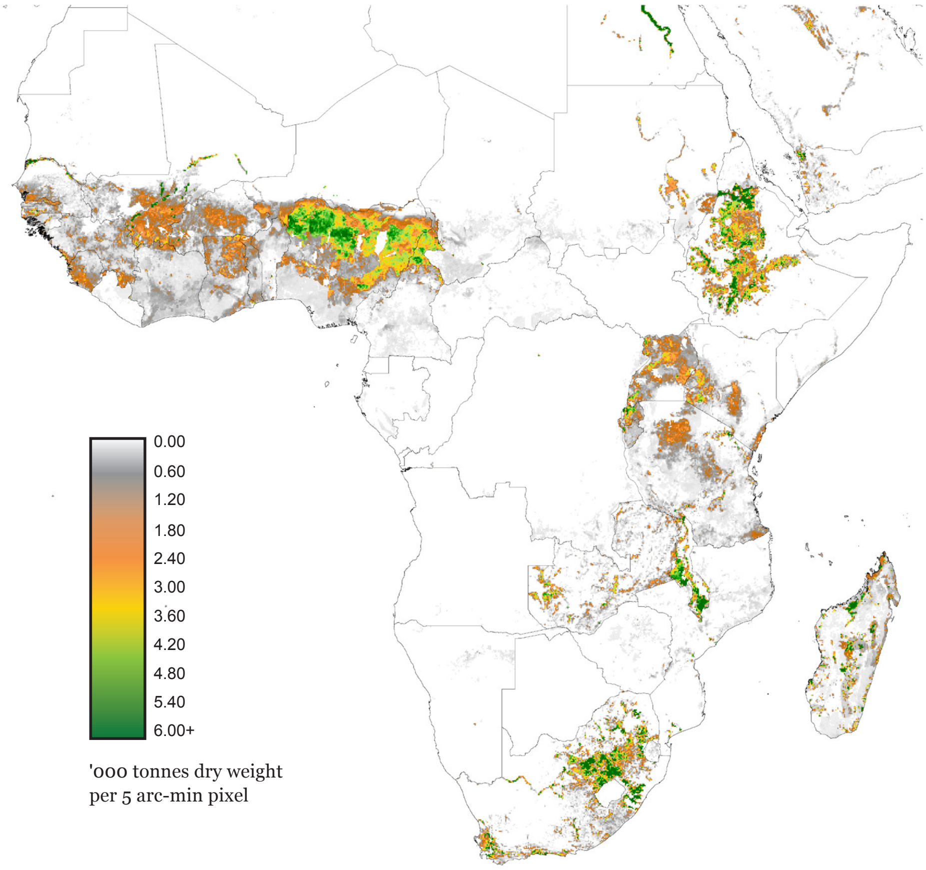
The map in Figure 10 shows the spatial distribution of crop residues (stalks, straw, sugarcane bagasse, tops and leaves) based on current patterns of agricultural production after allowing 2 t/ha to remain in the fields for soil protection. The highest biofuel production potential from crop residues is found in the southern Africa region owing to relatively high crop and residue yields.

It is important to note that in order to use crop residues for fuel production, these residues must be available in sufficient quantity to make the crop residue supply chain economically feasible. Substantial investments in logistics, transportation and storage are also required. Even more importantly, crop residues are also a major source of animal feed in large parts of sub-Saharan Africa, especially in a context where the availability of natural grazing is decreasing and livestock numbers are growing. Crop residues are widely used as lean-season feed, especially in small-scale production systems where grain stovers are sometimes grazed. To remain compliant with *RSB Principle 6: Local food security*, crop residues that are currently used for these purposes cannot be considered for fuel production, so the actual contribution of residues to the sustainable biofuel production potential in the sub-Saharan region will be less than 480 PJ.

However, crop residues could make a significant contribution to the biofuel production potential in some regions and countries, especially southern Africa (South Africa, Malawi, Zambia), Sudano-Sahelian Africa (Mali, Burkina Faso), the Gulf of Guinea (Nigeria) and eastern Africa (Ethiopia). For example, the current technical biofuel potential of prime and good quality REMAIN land in South Africa and Malawi amounts to 73 PJ and 8 PJ respectively, compared to available cereal crop residue potential of 70 PJ and 16 PJ respectively (2010).

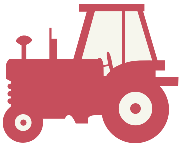
In addition, unlike REMAIN land, where the potential will decrease towards the 2050s because of expanding food production and climate change, **the quantities of crop residues potentially available will increase**. As a result, **future biofuel potential of crop residues may exceed the future biofuel potential from REMAIN land in several countries in sub-Saharan Africa**.

Figure 10: Spatial distribution of crop residues from current cropland, in 2010



Source: Own calculations

Potential agricultural job creation



Increased biofuel production is a great opportunity for job creation in rural areas, especially in less developed regions with a large share of the population employed in the agricultural sector. The number and kinds of jobs created depend on the crop type and applied management scheme, with a crucial factor being whether the harvest is brought in manually or mechanically. Because full mechanisation of feedstock cultivation can reduce labour inputs substantially, it is a critical consideration when it comes to generating employment.

Mechanisation of feedstock cultivation can substantially improve efficiency; however, this comes at the cost of labour inputs.

For most annual biofuel feedstocks, mechanisation can substantially improve efficiency and offer significant production cost advantages, so those farming activities are most likely to be fully mechanised. Production of the perennial grass miscanthus is likely to be fully mechanised, including field preparation, planting and annual harvesting. However, some perennial crops involve substantial labour inputs, especially for manual harvesting. For Solaris tobacco, seeds are usually harvested using manual labour.

Sugarcane production traditionally uses manual labour. It usually involves burning the spiky leaves of the sugarcane crop to reduce the risk of injuries during harvest and allow a faster cane collection process after burning. However, burning fields before harvest causes significant amounts of GHG emissions, impedes air quality and affects human health. Mechanisation and green harvesting are therefore increasingly promoted as a more beneficial and environmentally benign harvesting practice. It eliminates harmful emissions from smoke and increases the utilisation of biomass for energy generation in that the green tops are collected and used to generate electricity.

Cultivation of biofuel feedstock could create between 10 and 20 million jobs in the farming sector in sub-Saharan Africa.

Even if mechanisation is adopted where possible and economical, the job creation potential of dedicated crop production on REMAIN land is substantial. Our estimates suggest that between 10 and 20 million jobs could be created in the farming sector in sub-Saharan Africa, depending on the energy crop cultivated and the level of mechanisation its production allows. At the lower end of the estimate miscanthus – with its high level of mechanisation – dominates the crop mix, while at the upper end the mostly manual harvesting of jatropha and sugarcane would lead to higher job figures.

Siting possible biofuel production plants

For biofuel production to be viable, a minimum amount of biomass must be available within a certain radius around a biofuel production plant. The maps in Figure 11 shows the cumulative feedstock production potentials from prime, good quality and moderately suitable REMAIN land for vegetable oil-producing feedstocks for collection radiuses of (a) 50 km and (b) 100 km. It shows that bright spots of cumulative biofuel production potential based on vegetable oil occur in several locations in tropical sub-Saharan Africa, notably in the Democratic Republic of the Congo (DRC) and the Gulf of Guinea region. In these regions (green colour) the vegetable oil potential, mainly derived from oil palm cultivation, could supply biofuel plants with a capacity of more than 100 million litres.[4] Several other locations with main supplies from jatropha plantations could provide vegetable oil to biofuel plants of capacities between 30 million litres and 50 million litres.

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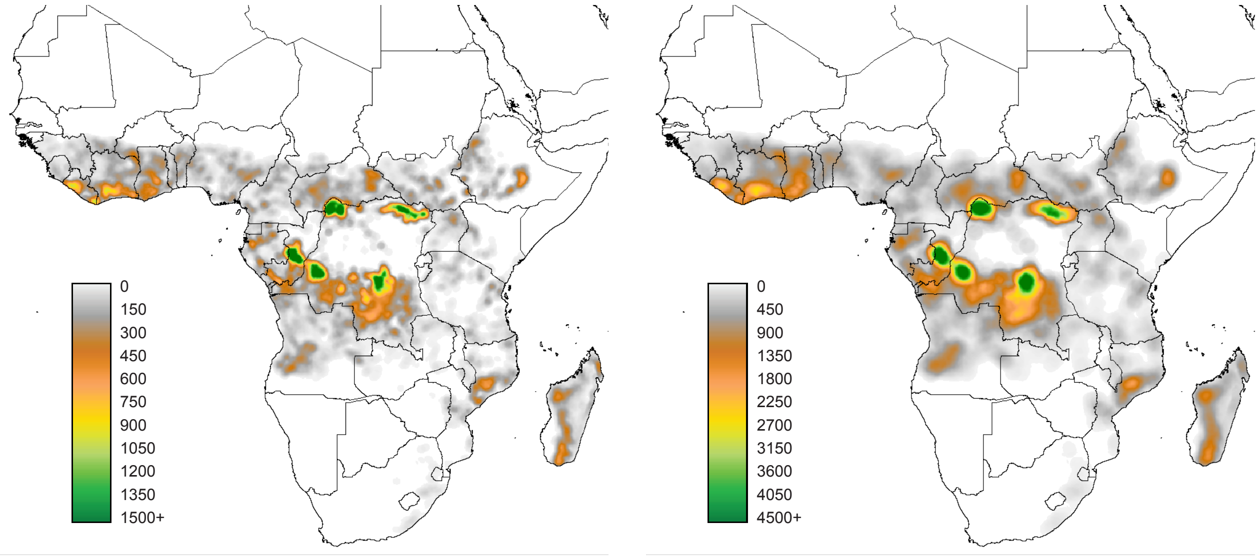
[4] 1 million litres of biodiesel are equivalent to 32.6 TJ.

WORKERS CARRYING SOLARIS SEEDLINGS

Figure 11: Present cumulative production potential of biodiesel (in TJ) from all rain-fed oil-producing feedstocks from REMAIN land in a radius of (a) 50 km and (b) 100 km*



a) Collection radius 50 km

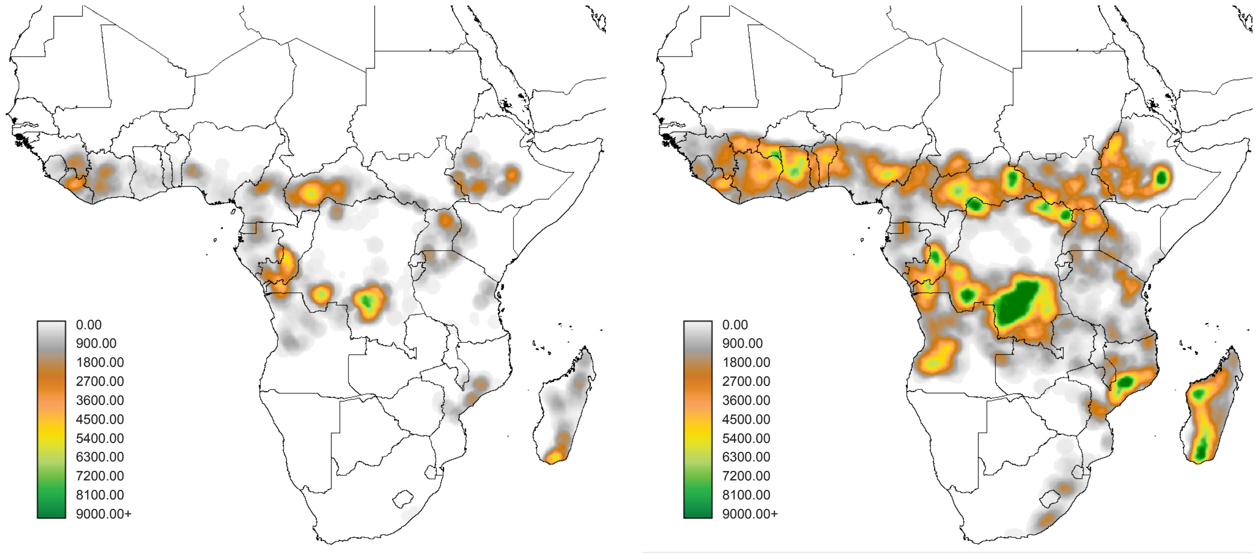
b) Collection radius 100 km

* The map shows the cumulative biodiesel production potential per grid-cell (in TJ) derived from the respective collection radius.
Source: Own calculations

Figure 12 highlights cumulative biofuel production potential for the sugar, starch and lignocellulosic biomass-based conversion pathways. Assuming only feedstocks for currently proven industrial-scale technologies (so not miscanthus), only sugarcane can meet the 60% GHG savings criterion for cultivation on rain-fed REMAIN land, with the highest concentration in central Africa (southern DRC, Republic of the Congo, Central African Republic). These regions could support large biofuel industries with an annual production capacity of more than 300 million litres per year (indicated by the green spots in Figure 12). The southern tip of Madagascar is another region with the potential for large-scale fuel production from sugarcane.

Construction of industries with an annual biofuel capacity of up to 150 million litres, represented by the brown to yellow spots in Figure 12, could be explored in Ethiopia, Uganda, Mozambique, Côte d'Ivoire and Liberia. Considering both miscanthus and sugarcane as feedstocks for biofuel production, significantly larger regions appear as potential production hotspots.

Figure 12: Present cumulative production potential of bioethanol on REMAIN land (in TJ) from (a) rain-fed sugarcane only and (b) sugarcane and miscanthus within a radius of 100 km*



a) Sugarcane only

b) Sugarcane and miscanthus

* The map shows the cumulative bioethanol production potential per-grid cell (in TJ)
Source: Own calculations

Additional sustainability considerations

In addition to sustainability evaluations and the application of detailed exclusion layers to protect the environment, biodiversity and future food security in this continental-scale study, there are sustainability aspects of biofuel feedstock production at the local scale that need to be considered.

The impact of biofuel feedstock production on biodiversity depends on a number of factors, such as:

- scale of operations
- degree of mono-cropping
- tillage methods
- use and management of agro-chemicals
- use of genetically modified organisms (GMOs)
- invasive characteristics of feedstocks.

These factors could combine to result in the following potentially negative impacts:

- Land conversion for mono-cropping without compensation by means of 'habitat islands' and 'migration corridors' may have far-reaching negative effects on ecosystems around the converted land.

- Conversion of grassland and shrubland may lead to over-exploiting nutrients and organic matter, inducing nutrient losses caused by soil erosion and compacting topsoil layers through the use of heavy machinery.

- Commercial agriculture often uses intensive fertiliser applications and biocides to control weeds or combat pests and diseases. Genetically modified organisms may require less input per unit output but may have a devastating effect on biodiversity.

- Toxicity of the biofuel
  feedstocks may negatively affect safe handling of the produce or other competing crops and plants and thus pose the risk of reducing biodiversity.

- Some of the assessed feedstocks are classified as potentially invasive species that could affect biodiversity well beyond the cultivated fields.

Although all these risks are eliminated or minimised by the RSB standard, the strict implementation of the standard at project level might further reduce the estimated biofuel production potential.

Sensitivity and uncertainties

Results produced in quantitative simulation studies are always subject to specific assumptions, sensitivities and uncertainties in data and parameters. The sensitivity analysis shows that the size of the sustainable biofuel potential is highly dependent on:

- the allocation of the GHG burden to the biofuel portion of multi-purpose crops
- the required GHG emission savings of biofuels compared to fossil fuels.

The processing of feedstocks and the conversion to biofuels often produces significant amounts of useful co-products (see Box 6). In this study, we apply value shares of co-products to allocate a fair share of GHGs from direct land-use changes to biofuels and co-products (e.g. animal feed). These depend on prices and technical conversion factors that are plant-specific. The lower the share of the GHG emissions allocated to the biofuel component, the easier it is for the biofuel chain to meet a GHG criterion. The higher the demand and price of co-products (e.g. press-cake or leaves for livestock feed), the lower the value share for the vegetable oil can be set. With fluctuations in price, the GHG allocation across all co-products of a multi-product plant should also change. In this study we addressed this by using long-term averages of prices for the various co-products. However, the picture at any given point in time can be quite different from the long-term average.

To analyse the impact on the potential of the GHG restrictions, we have analysed an alternative GHG criterion, which is somewhat less strict concerning the repayment period for direct land-use changes. As for the RSB-compliant GHG criterion, in this alternative GHG2 criterion, the emissions from LCA must be less than 40% relative to the fossil-fuel comparator. In addition, the repayment period for the initial carbon debt from land-use change must be less or equal to half the accounting period, i.e. repayment must be achieved within 10 years.

When applying the alternative GHG criterion, the estimated biofuel potential increases, the composition of the selected best-performing feedstocks becomes more differentiated, and the changes in biofuel potential between 2010 and 2050 are less severe compared to the RSB criterion. In locations where perennials cannot be grown without irrigation and annual crops are not able to meet the RSB criterion, crops admitted under the alternative, less strict GHG criterion could still produce large quantities of biofuel feedstocks and achieve substantial GHG savings. Annual feedstocks are more versatile and have better adaptation options in response to climate change.

LIMITATIONS

This study used best-available data to identify suitable areas for biofuel feedstock production on land that is not required for food production, environmental conservation or safeguarding key biodiversity areas.

Land excluded for food production considers projected future food requirements. Forests are generally excluded. Although 40% or 9.8 million km^2 has been set aside for 'ENVIRONMENT' across sub-Saharan Africa, including 30% of current grassland and shrubland (2.8 million km^2), **this study may nevertheless have missed some areas of importance for biodiversity and environmental conservation that have not yet been properly recorded in global databases**.[5]

The scenario approach used to estimate future food demand and related cropland use relies on two (out of five) Shared Socio-economic Pathways (SSPs) created in the context of the IPCC Fifth Assessment Report (IPCC, 2013). While **the two chosen development scenarios** (SSP1 and SSP2) were jointly elaborated and are widely used by an international research community, they **cannot cover all conceivable and possible trajectories of future food demand and associated cropland requirements**.

Finally, a limitation worth noting is the **lack of continental-scale reliable spatial data on the occurrence and severity of degraded land**. Biofuel feedstock production on degraded land could significantly increase the possibility, especially of annual crops, to meet the required 60% GHG emission savings criterion, which is often prohibitive owing to the soil and vegetation carbon losses that would be encountered in the conversion of REMAIN land. **Under conditions of land degradation before conversion of REMAIN land, the cultivation of biofuel feedstocks may actually increase the amount of carbon stored in soils**, but we were unable to quantify this in our study.

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[5] For example, in Madagascar approximately 80% of grassland and shrubland is not included in any of the data sources used in this study for defining exclusion areas of high value for the environment. At the same time, Madagascar is renowned for its high biodiversity and high degree of endemism (Ganzhorn et al., 2001). A similar concern is valid for the central African region.

CONCLUSION

This study presents an assessment of the biofuel production potential in sub-Saharan Africa in accordance with defined sustainability criteria.

The guiding assumptions for setting sustainability criteria are the principles of the Roundtable on Sustainable Biomaterials (RSB). Once food security and environmental sustainability criteria were accounted for, the balance of remaining land was explored for its suitability and capacity to produce a variety of biofuel feedstocks.

Summary of main results

At present, the agricultural sector employs about 70% of the labour force in sub-Saharan Africa.

Large investments are urgently required in sub-Saharan Africa's economies to foster GDP growth, boost employment opportunities, generate income and reduce the malnutrition and hunger which are once again on the rise on the subcontinent. A widely discussed option is to channel investments to the agricultural sector, at present employing about 70% of the labour force in sub-Saharan Africa. Sustainable production of highly demanded biofuels for the global aviation industry is seen as a possible option for tapping into sub-Saharan Africa's underutilised agricultural land potential.

The overall results of the study regarding the availability and productivity of land reserves in sub-Saharan Africa indicate the existence of **about 5.5 million km² of grassland and shrubland (termed 'REMAIN' land). This is over and above what is needed to achieve food security, land that is legally protected or land that should be set aside for nature conservation and environmental protection** (including forest land, key biodiversity areas and wetlands). **About 1.9 million km² or 32% of this REMAIN land** – an area larger than Tanzania, Kenya and Uganda together – **has been assessed as agro-ecologically very suitable or suitable for the production of some annual or perennial biofuel feedstocks.** However, exploitation of these land resources, requiring land conversion from natural grassland and shrubland to cropland followed by intensive feedstock cultivation practices, will result in **substantial initial carbon debts** owing to the removal of the existing vegetation and partial loss of soil carbon.

The strict sustainability greenhouse gas (GHG) saving criterion set by the RSB requires a minimum GHG emission saving of 60% relative to the fossil-fuel comparator when using a 20-year accounting period. **This criterion is mostly met by perennial biofuel feedstocks.** This is because these crops require less frequent and less intensive cultivation of soils when natural grassland or shrubland is converted for biofuel production.

Consequently, mostly land that meets the specific ecological growth requirements of perennial biofuel feedstocks can be considered. This restricts the choice of suitable rain-fed areas to mainly the subhumid and humid climate zones. Considering all 11 biofuel feedstocks evaluated in this study, only **0.8 million km² (or 15% of the total REMAIN land) is very suitable or suitable for biofuel feedstock production that would meet the minimum GHG savings criterion, if feedstock cultivation causes land-use change**. Potential feedstock candidates are miscanthus and jatropha (both currently not yet produced at economic scale in sub-Saharan Africa) and oil palm and sugarcane (traditional large-scale plantation crops in the region), which together could yield about 7 000 PJ of energy, or 165 mt of aviation biofuel.

Miscanthus, the most promising biomass feedstock, relies on second-generation conversion technologies. Because these technologies are not fully developed at commercial scale, introducing this crop in sub-Saharan countries would require significant investment. Experiences with the cultivation of jatropha has faced several challenges. These include irregular and sometimes low yields, invasiveness characteristics and the fact that jatropha seeds are poisonous to livestock and humans. The perennial nature of miscanthus and jatropha may limit farmer willingness to switch from the flexibility of cultivating annual crops to the longer time horizon required for the cultivation of perennials.

In addition, **the estimated biofuel production potential of the available REMAIN land in 2010 will likely be significantly reduced in the future. In response to future demographic changes and improved diets, land will be converted for food production.** Additional cropland for food production is likely to expand into REMAIN land with the most suitable conditions (climate, terrain, soil) for agriculture. Thus **available REMAIN land will decrease towards 2050 and some of the more suitable REMAIN land will be lost. Land suitability and yield impacts owing to climate change will further reduce potential biofuel production,** especially when the potential is largely based on perennial crops as a consequence of imposing a strict GHG savings criterion for soil carbon recuperation.

All these factors are expected to significantly reduce future biofuel production potential. Depending on the scenario, the amount of prime and good land allocated to the cultivation of biofuel feedstock in the future ranges between 400 000 and 500 000 km^2 (compared to 838 000 km^2 in 2010). Perennial feedstocks will suffer substantial production losses under the predicted effects of climate change and altered REMAIN land availability. This will cause **the overall future biofuel production potential from prime and good quality land to decrease by about 40% by 2050, to about 4 000 PJ**.

Restricting the choice of energy crops to perennials **may hamper options to involve small-scale production by local farmers and to integrate biofuel feedstocks in food, feed and fodder crop rotations**. This despite the fact that rotations of this nature would be beneficial to maintain soil productivity.

In addition to the potential from dedicated biofuel crops, **crop residues from the cultivation of food and non-food crops (food, feed and industrial) could contribute about another 7–9% to biofuel production potential in 2010.** However, conversion to biofuels requires second-generation technologies. Also worth noting is that the supply of crop residues will increase in the future, as food production will grow significantly.

Potential contribution of sustainable aviation biofuel from REMAIN land in sub-Saharan Africa to global aviation biofuel requirements

The ultimate goal of this analysis was to compare sustainable biofuel production potential with future aviation biofuel demand projections. ICAO recently proposed a volumetric target for aviation biofuel of 285 mt per annum, which is expected to be approximately 50% of the total fuel demand of international aviation in 2050 (ICAO, 2017). Although this target has not yet been approved, for argument's sake we compared this demand figure with the potential for sustainable biofuels estimated in this study. The aim was to give us an indication of what proportion of global sustainable aviation fuels could be produced from RSB-compliant crops on REMAIN land and from crop residues in sub-Saharan Africa.

Prime and good quality REMAIN land in sub-Saharan Africa, which complies with the GHG savings criterion, amounts to about 84 million hectares and could potentially produce – under current climatic conditions – an equivalent of about 7 000 PJ, corresponding to 165 mt of aviation biofuel per annum. If moderately suitable REMAIN land is also considered, then the total technical production potential is about 15 500 PJ (over 300 mt of jet fuel). However, the economic attractiveness of farming on moderately suitable land is uncertain. Profitability under moderate suitability could be achieved in case of high product prices, but this requires more detailed analysis.

More importantly in future, the potential for energy crop production on very suitable and suitable land is significantly reduced to about 4 000 PJ or 93 mt by 2050 with only a little difference between the SC1 and SC2 scenarios. This almost halves the potential compared to conditions in 2010. As discussed, the decrease is the result of reductions in the availability of REMAIN land, as well as the significant adverse impacts of climate change on agricultural productivity in general, and perennial tropical feedstocks in particular. If we assume that energy crops can be viably produced on moderately suitable land as well, the total future technical potential amounts to about 11 150 PJ or about 260 mt of jet fuel per annum (Table 10).

Table 10: Technical potential for RSB-compliant aviation biofuel from energy crops in sub-Saharan Africa relative to projected global demand for alternative aviation fuels

Alternative jet fuel demand by global international aviation in 2050	285 mt
Sub-Saharan Africa technical potential by 2050 from VS and S* land	93 mt
Sub-Saharan Africa technical potential by 2050 from VS, S and MS* land	260 mt
% of global international aviation demand that could be met by biofuels from sub-Saharan Africa	30–90%

* VS = very suitable; S = suitable; MS = moderately suitable
Source: Own calculations

In summary, our assessment suggests that **sub-Saharan Africa can at best contribute between 30% and 90% of future alternative aviation fuel demand in the form of RSB-compliant aviation biofuel, if alternative fuels are targeted at 50% of the total jet fuel demand from international aviation**. It is important to note that this amount represents the **technical potential**. The realisable **economic potential** will be a proportion of the technical potential. Furthermore, this is under the assumption that all energy crops on suitable REMAIN land in sub-Saharan Africa are used to produce biofuels for aviation and none are directed towards other uses (e.g. land transportation).

Potential contribution of sustainable aviation biofuel to domestic demand

While any biofuel feedstock produced in sub-Saharan Africa offers the opportunity for export earnings (at least initially), the longer-term ambition should be to develop sufficient domestic processing capacity. This would ensure that the benefits of the biggest value-add activities of the supply chain are realised in the region, and that the sustainable aviation fuel (SAF) market does not become another example of resource extraction from sub-Saharan Africa, with all the beneficiation and related industrialisation potential happening elsewhere. In addition, domestic production and consumption will achieve the largest GHG savings, which are reduced by the distance the SAF has to travel to market.

Because data on aviation fuel consumption and future projections in the region is very difficult to obtain, we were not able to contrast the total regional technical production potential with the total regional demand. However, we were able to do so for South Africa. The relevant figures are in Table 11.

In 2016, aviation fuel demand in South Africa was approximately 2 600 million litres.[6] Assuming a 3% annual growth rate,[7] without significant improvements inoperations and fuel efficiency, by 2050 domestic demand for aviation fuel could reach 7 000 million litres or 5.6 mt.

The current technical potential of RSB-compliant biofuel from energy crops on REMAIN land in South Africa is 73 PJ if only very suitable and suitable land qualities are considered, or 162 PJ if moderately suitable land is considered as well. This translates to approximately 1.7 mt and 3.8 mt, respectively, or 80–180% of the current demand. If agricultural residues that are in surplus to what is needed to maintain soil fertility are diverted to biofuel production, this could potentially add another 70 PJ or 1.6 mt of aviation biofuel, bringing the total technical potential to 5.5 mt or 260% of the total current aviation fuel demand.

Looking ahead, unlike most other countries, the biofuel potential in South Africa is actually projected to increase, mostly because the most promising energy crops will benefit from the positive CO2 fertilisation effect. The projections under the more sustainable SC1 scenario show an increase in potential on very suitable and suitable land to 152 PJ, and to as much as 269 PJ or 6.2 mt if moderately suitable land is also considered. Increases under scenario SC2 are similarly favourable at 164 PJ on very suitable and suitable land, and 272 PJ or almost 6.4 mt of fuel if energy crops are produced on moderately suitable land as well. However, because fuel demand is projected to grow faster than biofuel production potential, the potential contribution of biofuels to total aviation fuel demand decreases to 60–115%. Adding fuel production potential from agricultural residues brings the total future potential to over 140%.

Table 11: Technical potential for RSB-compliant aviation biofuel relative to projected domestic demand for aviation fuels in South Africa

	Current	2050 projection
Aviation fuel demand (in mt)	2.1 mt	5.6 mt
Potential from RSB-compliant biofuel based on energy crops on VS+S land	1.7 mt	3.5 mt – 3.8 mt (SC1) (SC2)
Potential from RSB-compliant biofuel based on energy crops on VS+S+MS land	3.8 mt	6.3 mt – 6.4 mt (SC1) (SC2)
% domestic demand that could be satisfied by energy crops in South Africa	80–180%	60–115%
Potential from agricultural residues	1.6 mt	> 1.6 mt
% domestic demand that could be satisfied by all energy crops and agricultural residues	260%	> 140%

Source: Own calculations

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[6] As published by the South African Department of Energy at energy.gov.za/files/energyStats_frame.html

[7] This is one percentage point lower than the 4% assumed by ICAO for long-term sector growth.

These figures are specific for South Africa. However, because in many countries in sub-Saharan Africa demand for aviation fuels is small (compared to more developed aviation markets), it may be possible to source a significant amount of alternative fuels that adhere to a high sustainability standard. And while the above figures relate to technical production potential – economic production potential is by necessity significantly smaller – they nevertheless indicate that sustainable biofuels can play an important role in decarbonising African aviation.

Main recommendations

This study offers a number of important insights on several aspects of sustainable biofuel feedstock production. These insights can be used to develop concrete recommendations for the advancement of sustainable aviation biofuels in sub-Saharan Africa:

1. There is meaningful potential for RSB-compliant aviation biofuel in the region, which may be substantially increased if the necessary investments are made to improve the quality of currently degraded land. There is therefore no reason to lower the sustainability bar to include unsustainable alternative fuels in the portfolio of fuels supplied to airlines.
2. Where the conversion of natural grassland or shrubland is involved, it is almost exclusively perennial biofuel feedstocks, requiring less frequent and less intensive cultivation of soils that can meet the RSB criteria. The willingness of farmers to invest in the cultivation of perennial energy crops depends on the long-term viability of the biofuel feedstock industry because it reduces the farmer’s flexibility in resource use compared to the cultivation of annual crops. This means the aviation industry and its fuel suppliers need to engage in long-term off-take agreements with feedstock producers to help them mitigate the risks related to the production of perennial crops.
3. While annual energy crops are rarely going to be a viable option in terms of GHG savings where conversion of virgin land to agricultural land is involved, they still have a role to play on degraded land (for example, restoration of degraded mining land). In addition, they could replace other industrial crops that are in decline, for example replacing traditional smoking tobacco with Solaris tobacco. Intercropping or rotation cropping could also help annual crops achieve compliance with the GHG savings criterion.
4. Shipping feedstock or even finished products across long distances can reduce the GHG savings from aviation biofuel to a point where it will no longer be RSB-compliant, so ideally, the finished products should be used where the feedstock is produced. This is a strong argument in support of the development of local biofuel value chains. The macroeconomic benefits of locally produced and consumed biofuel can go some way towards meeting sub-Saharan Africa’s developmental challenges, including energy security.
5. While the potential for sustainable aviation fuels from land-based energy crops can be considered significant, it is not going to be sufficient to meet projected global demand for alternative aviation fuels. Thus the development and commercialisation of alternative sustainable aviation fuel production routes must be stepped up to complement those that depend on land-based crops and agricultural residues.

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NOTES

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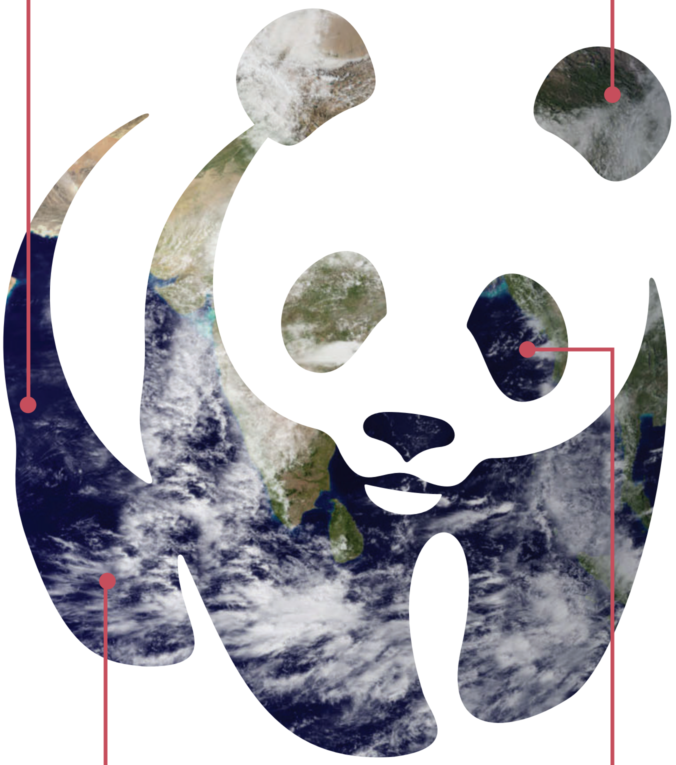
Understanding the sustainable aviation biofuel potential in sub-Saharan Africa



50%

Minimum reduction in net aviation CO2 emissions needed by 2050, relative to 2005 levels

30%

Proportion of global demand for alternative aviation fuels that could be produced in sub-Saharan Africa

150 000

Number of commercial flights already fuelled with a blend of alternative fuel

54%

Portion of land in sub-Saharan Africa needed to produce food and protect critical ecosystems

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To stop the degradation of the planet's natural environment and to build a future in which humans live in harmony and nature.

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