Working Paper

International Renewable Energy Agency

Estimating the Renewable Energy Potential in Africa

A GIS-based approach

About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international cooperation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

About KTH-dESA

The Royal Institute of Technology (KTH) is Sweden's largest technical university, providing more than a third of its technical research and engineering education capacity at the university level. Within KTH, the Division of Energy Systems Analysis (dESA) develops and applies quantitative energy and resource models to key development questions. The analysis undertaken ranges from understanding consumer behaviour to global development. Under these overarching goals, the division focuses on four core research areas, namely: S*ustainable Energy for All; strategic policies and investments; integrated climate, land-use, energy and water strategies to navigate the Nexus;* and the *Open Source energy Modelling System (OSeMOSYS.org)*.

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Acronyms

AEZ	Agro-Ecological Zoning
CSP	Concentrated Solar Power
DNI	Direct Normal Irradiation
GAEZ	Global Agro-Ecological Zones
GCR	Ground Cover Ratio
GHG	Greenhouse Gas
GHI	Global Horizontal Irradiation
GIS	Geographic Information Systems
ha	Hectare
IIASA	International Institute for Applied Systems Analysis
IRENA	International Renewable Energy Agency
Km	Kilometer
Km^2	Square Kilometer
KTH	Royal Institute of Technology
kW	Kilowatt
kWh	Kilowatt Hour
m	Meter
m^2	Square Meter
MW	Megawatt
m/s	Meters per Second
NPP	Net Primary Production
NREL	National Renewable Energy Laboratory
PV	Photovoltaic
PWh	Petawatt Hour
RET	Renewable Energy Technology
SHS	Solar Home System
TWh	Terawatt Hour

Executive Summary

This report presents an approach to quantify the power generation potentials for solar and wind energy resources in Africa, as well as an estimation of the bioenergy potential from selected first-generation biofuel crops. The analysis is based on Geographic Information Systems (GIS) data and has the aim to present a new methodology which can be further refined based on national and local situations and needs.

As a result of the analysis, the maximum technical potential based on geographic constraints will be given on a country-by-country basis for solar energy [both photovoltaic (PV) and concentrated solar power (CSP)], wind energy and bioenergy production. The report does not provide an in-depth analysis of specific renewable energy technologies (RETs) but aims to illustrate their potential on a general scale based on available resources and geographic constraints; its results are meant to help stimulate further investigation of specific technologies. Along with serving as a starting point for possible refined analyses, the report seeks to provide a transparent basis for large-scale renewable energy assessments. For this purpose, the underlying data and data-processing methodologies will be made transparent and reproducible.

This report estimates the geographic potential of renewable energy sources by applying a GIS approach. Such an approach can help to identify the most suitable areas for different RETs within a country, but can also indicate the general suitability of a country with regard to a specific energy source. This in turn can help policy makers to develop policy incentives for renewable energy sources of the highest potential and enable regional energy planners to appropriately reflect renewable energy contributions in their energy master plans.

The results clearly show the renewable energy hotspots which should receive the highest attention when renewable energy support schemes are being addressed or policies being formulated. Aggregated results for regions and countries are presented in the appendices in the form of tables and maps. Generally, investigated resources in this report are available throughout the continent. While wind energy has the largest regional disparities, solar resources have a significant potential in large parts of the continent (except Central African countries due to high levels of precipitation and cloud formation) but with notable differences when applied through different solar technologies – PV or CSP plants. The bioenergy potential of the continent is substantial but characterised by extreme disparities between regions – being highest in the equatorial regions and lowest in Northern Africa. Bioenergy crops may seem attractive as large land areas are still available for cultivation in many countries However, in light of the existing food insecurities and a growing population, this potential must be carefully re-evaluated. This report will only provide a first indication of biofuel suitability on a country level. Given the vast number of different possibilities for using biotic resources as a source of energy, this analysis can only provide an overview about the use of GIS methods to investigate the suitability of energy plants and their potential contribution to the energy system.

The national results presented in this report are interesting for a number of reasons: firstly, the size of a country naturally has an influence on the expected potential; secondly, the analysis also shows that although the five African regions (Northern, Western, Southern, Eastern and Central) have relatively similar areas, their overall potential for renewable energy sources is relatively different. This indicates that the regions need different strategies to develop their resources, but at the same time regions can extensively benefit from a better interconnection and increased information exchange of the five regional "power pools".

The results presented in this report and additional analyses based on alternative GIS layers will be made publicly available and accessible on IRENA's Global Atlas website (http://globalatlas.irena.org) as well as on the KTH-dESA website (http://www.desa.kth.se).

1. Introduction

Reliable energy resource estimates are the foundation of energy planning – this includes "conventional" energy sources or fossil fuels as well as renewable sources. The assessment of current and future production of fossil fuels has been undertaken for many years on different scales by using elaborate methodologies. However, comprehensive approaches for estimating national energy production potentials from renewable energy sources are still few and often not transparent. This is especially the case for developing countries. This report intends to help overcome this gap by providing indicative estimates of the solar, wind and biomass energy potential in every African country. These estimates can be used for transparent energy modelling and energy systems analysis, which is the basis for proper energy planning.

While setting up the corresponding energy models, it became apparent that no complete and transparent account of renewable energy potentials of African countries is freely available (despite a number of country assessments and a large amount of available raw data). We have therefore systemised and combined available data in order to develop a renewable energy database for Africa. The data used in our analysis are partly based on freely available open-source GIS maps. All data are referenced in the corresponding sections of the report and described in detail (including their respective uncertainties and spatial resolutions) in Appendix D. The hope is that the data, together with the corresponding national energy models, will give governments and decision makers a basis to work from when elaborating energy and cost-efficient roadmaps for the future.

The renewable energy potentials are mainly calculated from renewable energy resource maps, available meteorological data and other geographic information including land cover, land use and topographical maps.[1] As a final result, a resource potential assessment for different general RETs is calculated. Technologies include:

- Conventional high-temperature CSP
- PV in grid-connected large-scale applications, excluding roof-top systems
- Wind energy in large-scale grid-connected wind farms
- A first approximation of selected exemplary energy crop production potentials, based on generalised agricultural parameters.[2]

For this analysis, a number of GIS tools were used to create a multilayer representation of a chosen geographic area, which enables the user to store, manage, represent and analyse a very large variety and quantity of geographic data. Each "layer" contains a certain type of information which can be "superimposed" on or linked to other layers to create a comprehensive representation of the studied area. Within this study we used several GIS layers to define the suitable available land area for certain types of RETs, and subsequently combined these areas with resource data such as solar irradiation and wind speed data, or agro-climatic maps indicating the area's suitability for certain biofuels.

The results of our approach are presented in the form of tables and maps in Appendices A, B and C. The study establishes a methodology and framework which allows further refinement as more data become available. Potential refinement will include the use of additional parameters to enable a more exact geographic localization of the most suitable areas, use of finer geographic coverage and higher resolution data, or potential development of future scenarios under different land use, climate and population projections. It should be clearly pointed out that this analysis can and should serve as a transparent blueprint and basis for an improved and more detailed analysis of renewable energy potentials at national level.

[1] *For the analysis, open-source freely available data have been used for all maps except for solar irradiation and wind speeds. References to related data sources are available in footnotes and are described in more detail in Appendix D.*

[2] *The assessment of the bioenergy potential is by no means exhaustive and does not include a wide range of alternative bioenergy production options (e.g. biogas, waste-to-energy, modern 2nd-generation options). The analysis used here covers large-scale biofuel cultivation as this option is highly location- and area-dependent and can be well analysed using GIS technology, which is the main focus of this report.*

2. Methodology

When investigating the potential of renewable energy sources, we distinguish between different "categories of potentials" that require a series of processing steps and assumptions. Cascading down from a theoretical potential (*e.g.* the overall amount of solar irradiation that reaches a country or the overall theoretical energy of the wind at a given location) to the technical or implementation potential involves introducing a series of additional data assumptions. These steps are similar for different renewable energy resources but certainly require different parameterisation such as different restriction parameters.

Table 1 gives an overview of the cascading nature of the different potential definitions.

Table 1: Different "levels" of renewable energy resource potentials

Type of Potential	Description
Theoretical Potential	The theoretical potential describes the amount of resource available without considering any conversion efficiencies and losses; this equals the maximum amount of energy that is physically available from a certain source. In the case of solar energy, this would be equal to the total solar radiation impinging on the evaluated surface.
Geographic Potential	The geographic potential may be seen as an intermediate step towards calculating the technical potential of renewable energy resource. The geographic potential takes into account areas which are suitable and usable for specific renewable energy employment. Depending on the details of available geographic data, an appropriate set of exclusion criteria can be set to realistically estimate the available land area (*e.g.* exclusion of urban areas for large scale wind power production, protected land, sloped areas, water bodies).
Technical Potential	The technical potential is the geographic potential minus the losses from conversion into secondary energies and constrained by the requirements related to large-scale installation (*e.g.* spacing factors representing spacing and servicing areas of solar power plants or wind turbines, as well as (grid-) transportation losses). Technological, structural, ecological, and legislative restrictions and requirements, are accounted for. The calculation of the technical potential of bioenergy sources is additionally complex as the resulting product or "harvest" is subject to further conversion processes. Depending on the type of biocrop produced, these conversion processes may range from simple combustion to advanced conversion processes. This report will only give an indication of the amount of potential biomass – without taking into account further processing.
Economic Potential and Implementation Potential (not part of this analysis)	Economic potential is the proportion of the technical potential that can be utilised economically. It takes into account costs and other socioeconomic factors (*e.g.* fuel and electricity prices, other opportunity costs, land prices). Economic and Implementation Potentials are not part of this study.

Source: GWEC et al. 2012 modified by the authors

Within our analysis we adopted a three-step approach:

- First, we define "exclusion and inclusion zones" for applying different RETs based on geographic data (in GIS format).
- Second, we combine the prepared "inclusion zones" (areas where different RETs are technically applicable) with maps showing the theoretical potential of different renewable energy sources (sun, wind and biofuels). By doing so, we extract sound geographic potential values for the target area.
- In a third and last step, we introduce efficiency and conversion factors for solar and wind technologies and include spacing requirements to show resulting technical potentials. In the case of bioenergy crops, we will only give an indication of the amount of potential biomass available – without taking into account further processing. As different bioenergy crops require different further processing and conversion steps, a detailed analysis goes beyond the scope of this report.

In the approached used (which will be described in more detail in sections 2.1, 2.2 and 2.3), a number of geo-processing steps need to be performed with the data in order to harmonise inputs. Figure 1 gives an overview of the data handling in our analysis and the steps involved in attaining country-level tabulated data. This specifically includes data harmonisation and geo-referencing (i.e. the synchronisation of extents and coordinate systems used).

Figure 1: General structure of GIS data collection and processing

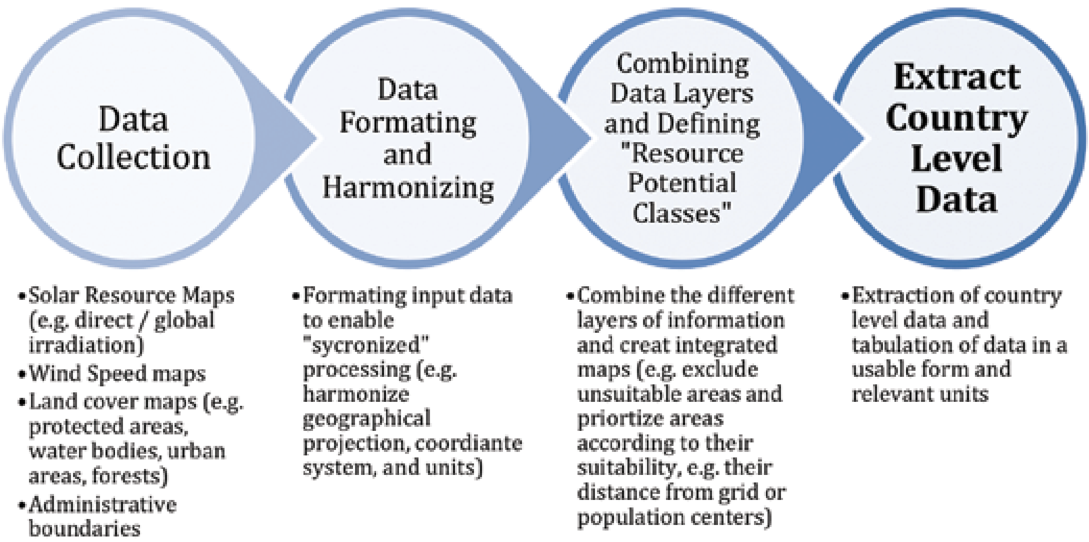


Figure 1: General Structure of GIS data Collection and Processing (author's illustration)

Source: own illustration

2.1 Step 1: Developing Exclusion Maps

Due to the strong regional and temporal differences of renewable energy resources, it naturally becomes difficult to make informed assumptions on a global level. Renewable energy assessments might be based on different data sets or perhaps developed using different methodologies or boundary conditions, making it difficult to compare them. This problem and other general issues associated with assessing regional differences (*e.g.* taking into account in geographic features such elevation or exiting land cover) can be overcome and managed through the use of global or continental GIS data sets and maps, which are a useful tool for resource potential and distribution analysis. GIS data can store location dependent features and characteristics in a smart way, making it possible to combine (or extrapolate) certain features of a location.[3]

[3] *As an example, this capability may serve to build a CSP plant at a specific location: Using a set of separate maps (e.g. slope, irradiation, land cover), with the help of GIS processing it becomes possible to define "threshold variables" (e.g. slopes greater than a defined percentage, low irradiation, certain land cover such as water bodies and forests) and define all land areas that possess one or more of these characteristics as an "exclusion zone" not suitable for CSP.*

GIS-related data from ground observation and satellite measurements are often publically available: these data provide a transparent and flexible option to combine and interlink the wealth of different data or natural features. Natural geographic features (*e.g.* slopes, elevation, land use, water bodies) can also be combined with available social data (*e.g.* population density, poverty data) or technical infrastructure (*e.g.* roads, power grids). A complete list of the publically available GIS data used in this report plus additional resources can be found in Appendix D.

For the development of exclusion maps, a set of given screening criteria was used. While some of the screening parameters are similar for all RETs investigated, others are different due to different technical requirements with regard to terrain (*e.g.* sloped areas are suitable to a certain degree for PV and wind but completely unsuitable for CSP). It is important to note that in the case of biomass our assessment only covers energy crop production areas which are currently unused and do not interfere with current food production. Thus, for example, forest areas and currently used agricultural lands are part of exclusion zones for the biomass assessment. Table 2 gives an overview of the general parameters and their application for different renewable energy sources.

Table 2: Overview of general screening parameters used for preparation of exclusion zones

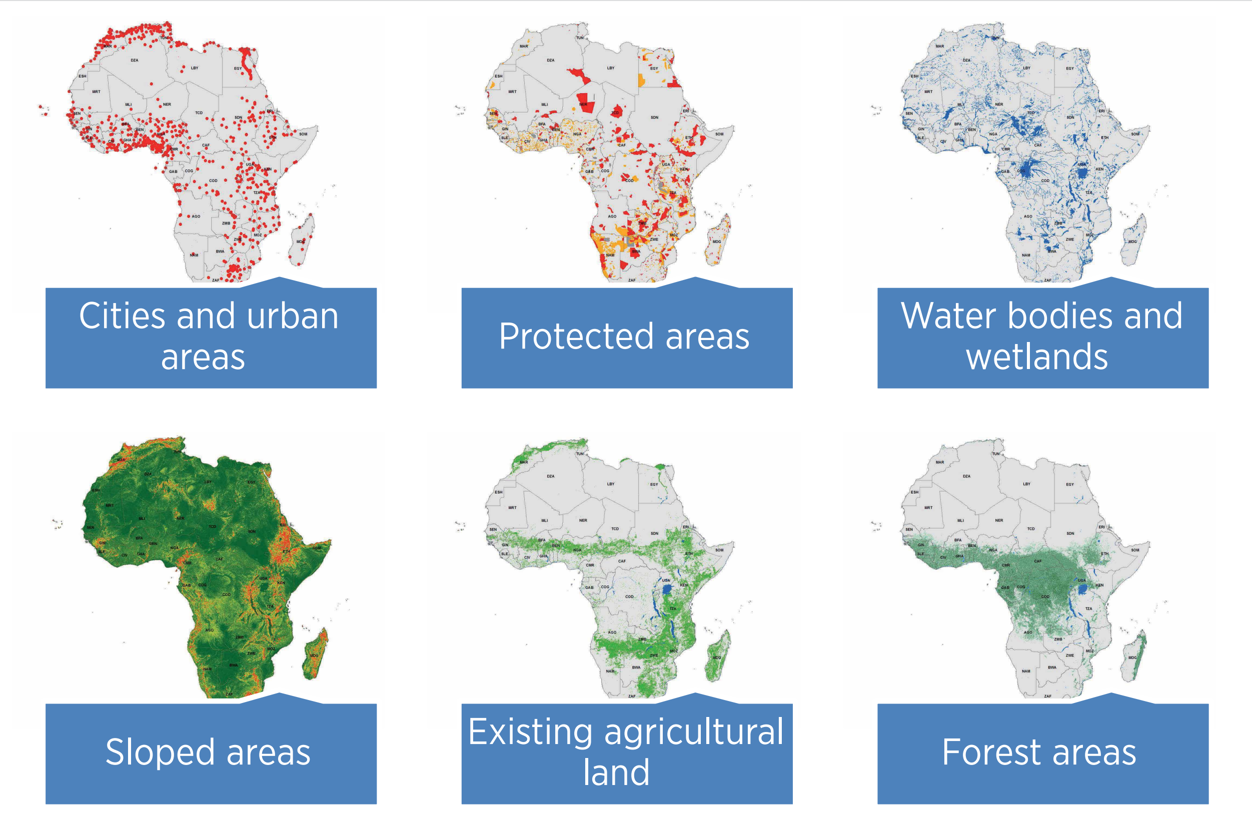
General exclusion parameters	Values for different renewable energy technologies
Cities and urban areas	Excluded for all RETs – in a follow-up refined analysis the inclusion of urban areas may be considered to approximate roof top solar applications. In our analysis, which mainly focuses on large-scale applications, urban areas have been excluded.
Protected areas	Excluded for all RETs – this is a very conservative assumption as some specific smaller-scale technologies in line with certain requirements may be developed within certain types of protected areas .
Water bodies (including wetlands, and floodplains)	Excluded for all RETs.
Sloped areas	In the case of CSP – all sloped areas with slopes steeper than 2.1 degrees were excluded.
	In the case of PV and wind areas – slopes larger than 45 degrees were excluded.
Agricultural land	Land areas (grid cells) identified as solely used for agriculture have been excluded from the calculations for PV and CSP potential but are considered in the case of wind potential assessment. For the calculation of potential biofuel production, current agricultural land areas have been excluded. As a result only currently unused or marginally used land resources are considered – this approach has been taken to prioritise currently used lands for food production.
Forest areas	Excluded for all RETs.

The exclusion parameters were combined into an overall exclusion map and subsequently subtracted from the survey areas.[4] Figure 2 illustrates the different restriction parameters applied while producing a restriction map.

[4] *Initial restriction maps were produced and provided by "D. Stetter, Deutsches Zentrum für Luft- und Raumfahrt (DLR), German Aerospace Center" according to the set of previously outlined parameters. Subsequently, restriction maps were produced by KTH and are available upon request.*

While Table 2 illustrates "hard" criteria for the analysis, such as underlying geographical restrictions, Table 3 presents "soft" or optional criteria, which are not technical necessities but could significantly affect the cost-effectiveness or economic justification of implementing the proposed RETs. These restriction criteria are NOT used in the current analysis but can be adjusted and applied to the underlying approach to refine results according to specific regional requirements (*e.g.* water availability, distance to grid, population density).

Figure 2: Overview of restriction zones applied



Source: own illustration

Table 3: Overview of optional screening parameters used for the preparation of exclusion zones

Optional exclusion parameters for further investigation of different scenarios	
Distance to urban areas	A further optional criterion sets a maximum distance of 200 km to the nearest city (50 000 inhabitants or more). This avoids accounting for extremely rural areas (*e.g.* associated with prohibitively high transmission costs for large-scale renewable electricity systems). This approach can be useful if no data on grid connections or planned grid connections are available.
Distance to existing grid lines	An alternative optional criterion can be established to exclude all areas exceeding a certain distance to the existing electricity grid. (Again this can be used to avoid areas with prohibitively high transmission costs.)
Market access	Established map data on the "distance to market" exist for the African continent. These data (measured in travel time over 12 hours to nearest city) can be used as a proxy for the remoteness of an area. Optional exclusion zones that consider areas not within reach in a given timeframe can be established using this indicator.
Water availability	Specifically for the analysis of CSP as a water-requiring technology, the distance to water sources (water bodies and rivers) can be used as a further optional exclusion criterion. Generally the application of CSP using dry cooling towers and air cooling is possible, but leads to lower overall efficiencies and higher capital costs.

In the next and subsequent steps, the "hard" restriction maps for the different RETs are combined with resource data.

2.2 Step 2: Combining Restriction Maps with the Resource Maps

2.2.1 A closer look at the investigated energy resources

After defining the restriction areas, the resulting maps are combined with the resource maps for solar and wind energy as well as with maps for potential production of biofuels.

For solar and wind resources, resource availabilities are further grouped into suitability classes.

For solar energy, three and four classes were considered for PV and CSP applications.[5] For wind energy, seven classes were defined. The chosen classes represent the different suitability levels for the respective technology and are based on general "boundary conditions" defined in consultation with IRENA. The selection of these values does have a significant impact on results and should be transparent to enable a responsible interpretation of the results. They may be a topic for discussion with different ranges of optimal suitability defined in different literature. Nevertheless, the values used here can be considered as sound assumptions which serve to identify best locations on the continent (without taking into account seasonal and yearly variations). The following tables (Table 4 and Table 5) give an overview of the suitability classes chosen for different technologies.

[5] *For the analysis, both solar irradiation measure (Global Horizontal Irradiation – GHI – and Direct Normal Irradiation – DNI) were used. While GHI better approximates the PV cell output, DNI better approximates CSP plant output. A summary explanation is that GHI includes direct and diffuse radiation, while DNI only considers the direct beam, which represents a better proxy of the energy which can be concentrated by mirrors in CSP plants. DNI intensity is strongly diminished by clouds, water vapour and aerosols such as dust, pollen and soot particles.*

Table 4: Suitability classes of solar irradiation according to technology (PV and CSP)

	Limited suitability	Suitable	Highly suitable	Excellent
Photovoltaic (PV)	below 1 000 kWh/ m²/year (GHI)	1 000 –1 500 kWh/ m²/year (GHI)	1 500 – 2 500 kWh/ m²/year (GHI)	2 500 – 3 000 kWh/m²/year (GHI)
Concentrated Solar Power (CSP)	below 1 800 kWh/ m²/year (DNI)	1 800 – 2 000 kWh/ m²/year (DNI)	2 000 – 2 500 kWh/ m²/year (DNI)	2 500 – 3 000 kWh/m²/year (DNI)

Note: kWh = Kilowatt hour; m² = square meters

Table 5: Suitability classes of average annual wind speeds at 80 m

	Not suitable	Limited suitability	Suitable		Highly suitable / Excellent		
Wind Energy	0-4 m/s	4-5 m/s	5-6 m/s	6-7 m/s	7-8 m/s	8-9 m/s	>9 m/s

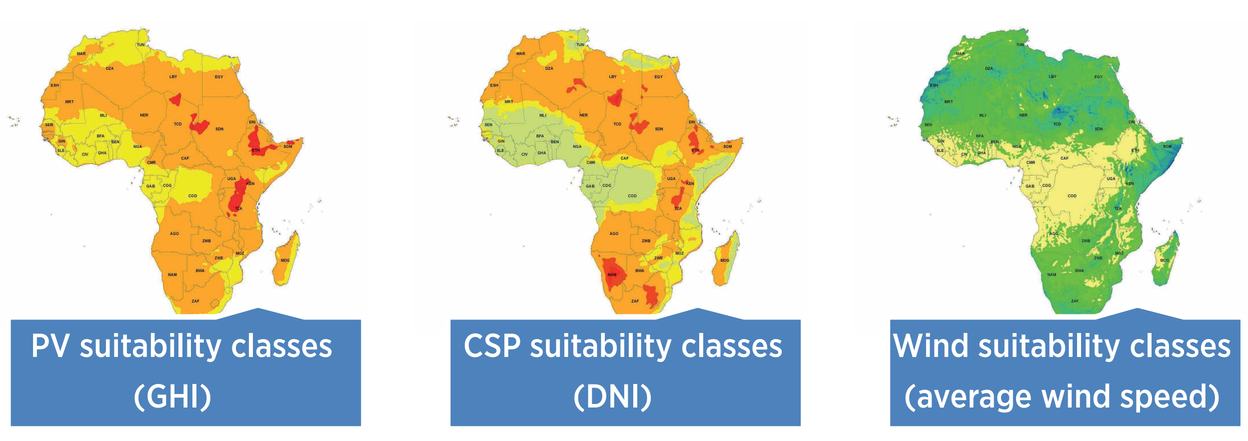
Note: m/s = meters per second

Due to a lack of detailed information (no temporal wind speed distribution tables were available for this analysis), the wind resource assessment should only be seen as a first pass approach. Local resource mappings are a prerequisite for any exact wind project siting studies.[6]

Figure 3 gives a graphical illustration of the geographic locations best suited to PV, CSP and wind energy production.

[6] *Wind speed distribution patterns for Africa are available at a much coarser resolution of 40 km grid size from NASA (http://eosweb.larc.nasa.gov/). Currently, a re-evaluation of the wind energy potential including these distribution data is under way and will be available in due time; this analysis will also include the monthly distribution of wind power in Africa.*

Figure 3: Overall resource potential for PV, CSP and wind technologies



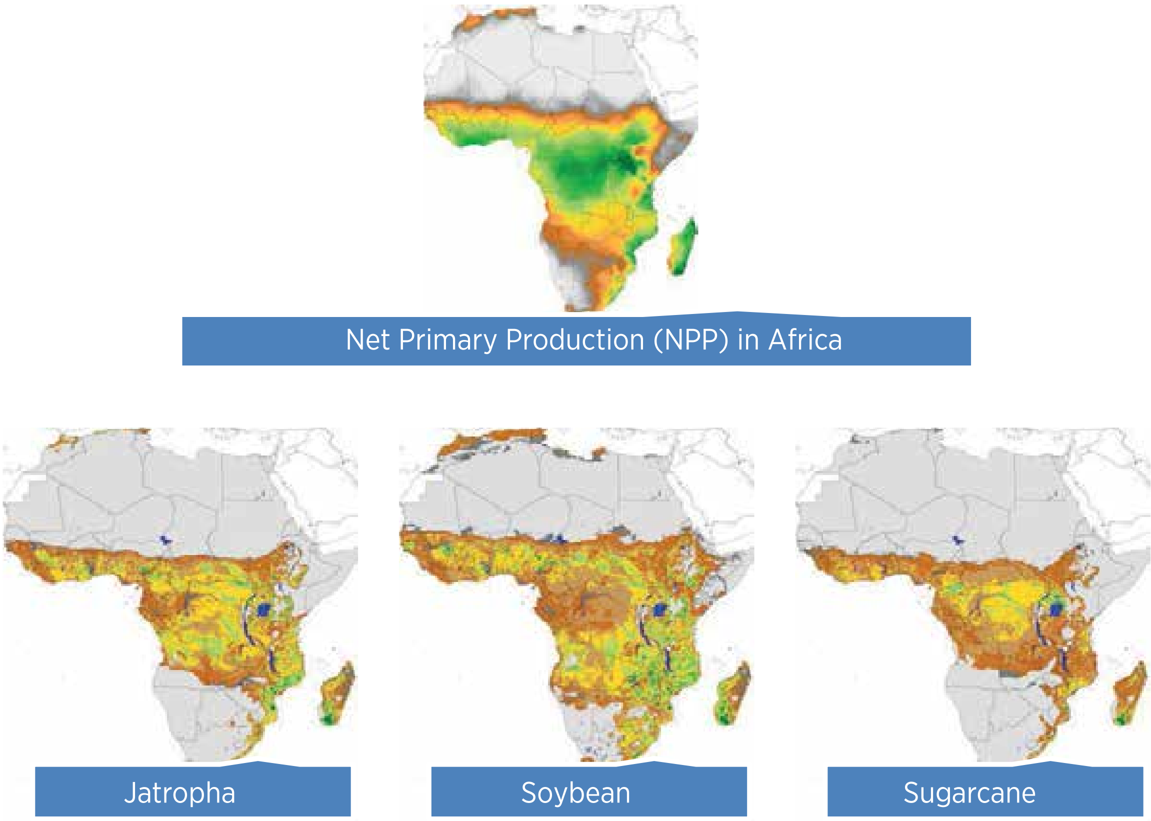
Note: Potentials calculated based on solar irradiation and average wind speed. Dark orange and red areas indicate best suited locations for solar energy systems while dark green and blue areas are best suited for wind. Different suitability classes are illustrated according to Tables 4 and 5.

Source: own illustration

For biomass, our analysis covers production potential of three energy crops: sugarcane, soybean and Jatropha. The Net primary production (NPP) of biomass is used as an approximation for overall agricultural suitability. The NPP is directly dependent on land resources, temperature, moisture and solar irradiation and can be described as the potential for production of plant matter. NPP is estimated as a function of incoming solar radiation and soil moisture and is a quantitative proxy for the photosynthetic activity of a plant. Further analysis based on basic agro-climatic indicators is conducted using the Global Agro-Ecological Zones (GAEZ) model developed by the International Institute for Applied Systems Analysis (IIASA) (Fischer *et al.* 2011; IIASA & FAO 2012) to define crop-specific suitability classes for selected conventional biofuel crops. The three crops have been chosen because they are generally suitable for cultivation in Africa and have recently received a lot of attention; additionally all three crops have good data availability within the GAEZ model and are already grown on the continent.

The GAEZ tool is a GIS-based model that makes it possible to show regional patterns and identify the most suitable countries and regions for certain crop types. The general resource potential for bioenergy is illustrated in Figure 4 using NPP as a proxy for agricultural suitability (top part of the figure) as well as the three selected biofuel crops and their suitability according to "suitability classes" (lower part of the figure).

Figure 4: General illustration of suitability areas of bioenergy production



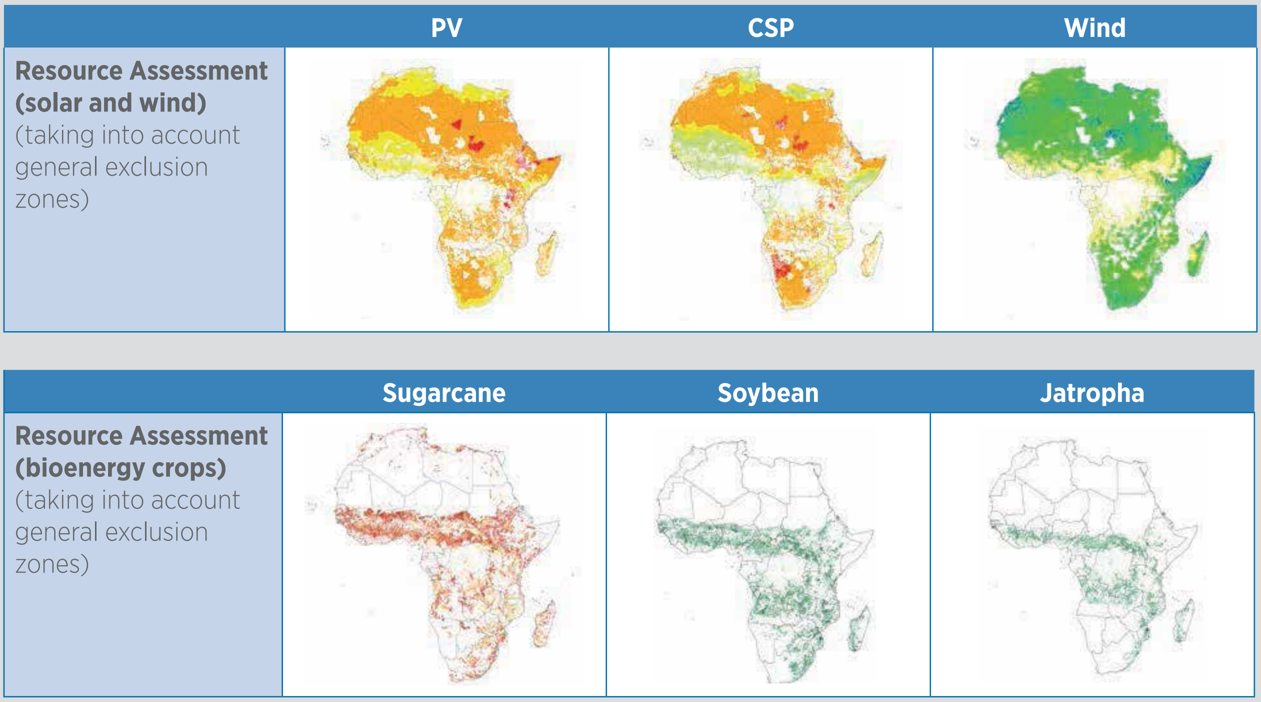
Source: GAEZ, own illustration

Assessing the potential of bioenergy resources is particularly complex as suitability areas change with agricultural practices (*e.g.* irrigation practices, input of fertilizer) as well as with shifting climate patterns. The difficulties of assessing bioenergy potentials are explained further in section 3.4 "Bioenergy".

2.2.2 Producing final potential maps and country-level results

After the resource maps have been prepared as described above, they are combined and superimposed onto the exclusion maps. The resulting maps, combining exclusion areas and "resource classes", can be seen in Figure 5 (in more detail in Appendix B, Figures 11, 12, and 13).

Figure 5: Resource potential "suitability" combined with the "exclusion map"



Source: own illustration

Note: In the case of CSP and PV, green and bright yellow represent low suitability, orange medium suitability and red high suitability; in the case of wind, darker shades of green represent higher wind speeds and better "suitability". Maps in the lower part of the figure represent areas suitable for biofuel production after applying restriction criteria (colours indicate the potential of the crops with reference to optimal yields without artificial irrigation (generally yields for un-irrigated sugarcane are relatively low (red colour) in comparison to soybean and Jatropha.

The resulting maps and their underlying data can be exported (on a country basis) from the GIS software into a database or spreadsheet programme to work with the resulting land areas for each of the African countries. The total area – restricted area as well as the areas for the resource potential classes (from "not suitable" to "excellent suitability") – for each country is summarised in resulting tables in Appendix B (Table 11 for CSP, Table 12 for PV, Table 13 for wind).

As an example, the wind energy potential of Uganda is shown in Table 6. Aside from the relevant area categories, this table also shows how much country surface "receives" which level of average wind speeds. As a result, 17 348 km^2 of total land area is suitable for wind energy production (and 1 313 km^2 highly suitable), which corresponds to 7.2% (and 0.5%) of the land area.

Table 6: Results table for Uganda indicating wind speed areas as part of the total survey area

Country	Total Country Area	Exclusion Area	Yearly Average [m/s] of Wind Speed							
			< 4 m/s	4–5 m/s	5–6 m/s	6-7 m/s	7-8 m/s	8-9 m/s	9-10 m/s	10-11 m/s
			not suitable	limited suitability	suitable		highly suitable/excellent			
	[km²]	[km²]	[km²]	[km²]	[km²]	[km²]	[km²]	[km²]	[km²]	[km²]
Uganda	241 540	30 862	142 623	50 707	10 561	5 474	1 313	0	0	0

Note: The methodology described above is used to define exclusion areas.

2.3 Step 3: Developing the Technical Resource Potentials

In this last step, the renewable energy potential in the identified areas is converted into realistic technical potentials. The aim is to assess maximum potentials for different African countries for the investigated RETs.

This potential is calculated from the available resource maps by multiplying the respective resource data with efficiency factors, as well as applying factors for spacing requirements.

The calculation of the technical potential is technology-dependent due to different conversion efficiencies, space requirements and power characteristics. Solar photovoltaic plants have a near linear relationship between the amount of irradiation and expected electricity production. On the other hand, when considering CSP, the relationship between resource (irradiation) and energy output is more complicated due to increased efficiencies of CSP plants under higher irradiation. In the case of the wind resource assessment, resource availability plays the most significant role as energy production is not linearly dependent on the wind speed but has a near cubic relationship.[7] As pointed out above, the calculation of the technical potential of bioenergy sources is additionally complex as the resulting product or "harvest" is subject to further conversion processes. Depending on the type of biocrop produced, these conversion processes may range from simple combustion to advanced conversion processes. This report will only give an indication of the amount of potential biomass – without taking into account further processing. In a more detailed analysis, the resulting biomass/biofuel harvest can be converted into final energy amounts depending on the conversion process chosen and applied in country.

The next sections give an overview of conversion assumptions used in the analysis for each of the investigated renewable energy sources.

[7] *In the case of wind energy, in theory a doubling of the wind speed means an eight-fold increase in the "energy potential of the wind", which relates to the potential energy that can be usefully converted in wind turbines.*

3. Deriving Technical Potentials from the Identified Resource Areas

3.1 Solar PV

For calculations of solar PV potentials on the African continent, efficiencies and conversion factors which are characteristic for typical large-scale grid-connected systems are used. The specificities of solar home systems (SHS) and solar-powered mini-grids are not covered in this report.

As indicated in section 2.2.1, solar PV production linearly depends on resource availability (solar irradiation). To develop the technical potential for a given area, the following formula (Equation 1) was applied.

Equation 1: Basic formula for the development of technical solar PV potentials

Equation:	Solar Resource Availability	x	PV Module Efficiency	/	Spacing Factor	x	Available Area	=	Technical Potential
Units:	$kWh/m^2/year$		[%]		[-]		[km^2]		[GWh/year]
Example Values:	2 000		16.5		5		100		6 600

Note: GWh = Gigawatt hour

Solar Resource Availability is given by the sources mentioned in Appendix D and specifically in the section on Solar. For each location on the African continent, values for DNI and GHI are available. For the solar PV technology, we use the GHI value as it presents a close correlation to the amount of energy produced.

PV Module Efficiencies are available at the National Renewable Energy Laboratory (NREL).[8] As a conservative efficiency value for commercial solar cells (multi- and polycrystalline cells), our analysis assumes a PV module efficiency of 16.5%. Transmissions and distribution losses are not taken into account.

Spacing Factor or alternatively the "ground cover ratio" (GCR) or footprint is a value for estimating the actual land use (ground areas) compared to the area of the actual panels (or mirrors in the case of CSP). This factor depends on the type and characteristics of the PV plant, but an average factor for large PV installation is on the order of 5 (meaning that the ground area needed is 5 times higher than the actual area that "collects" solar radiation (see also (IFC 2012)). For PV the main factors which lead to additional space requirements are collector spacing areas, and electrical equipment especially for large scale applications.

Available Area is equal to the area calculated in the GIS analysis, taking into account exclusion zones and areas without sufficient resource as well as "secondary" exclusion zones such as remote areas.

[8] *Available at the NREL Photovoltaic home page* (http://www.nrel.gov/ncpv/) and specifically at: http://www.nrel.gov/ncpv/images/efficiency_chart.jpg.

3.2 Solar CSP[9]

In the case of CSP (in contrast to PV), the relationship between resource (irradiation) and energy output is more complicated due to increased efficiencies of CSP plants under higher irradiation. Therefore site specification of CSP plants is even more important than for PV. Otherwise the calculation is similar to solar PV and a basic formula for CSP is indicated below:

Resource Availability is given by the sources mentioned in Appendix D under the subheading Solar. As mentioned above, for each location solar irradiation values (both DNI and GHI) are available for each location. For the CSP technology, the DNI value is used as a better proxy to estimate final production. Using solely DNI values for estimating CSP performance certainly has drawbacks, as lower-level aerosols (such as dust and humidity) are not captured sufficiently by this kind of satellite data. Experience from the Middle East shows that areas with similar DNI values still can have significantly different CSP yields depending on local conditions, for example with respect to dust or mist formation.

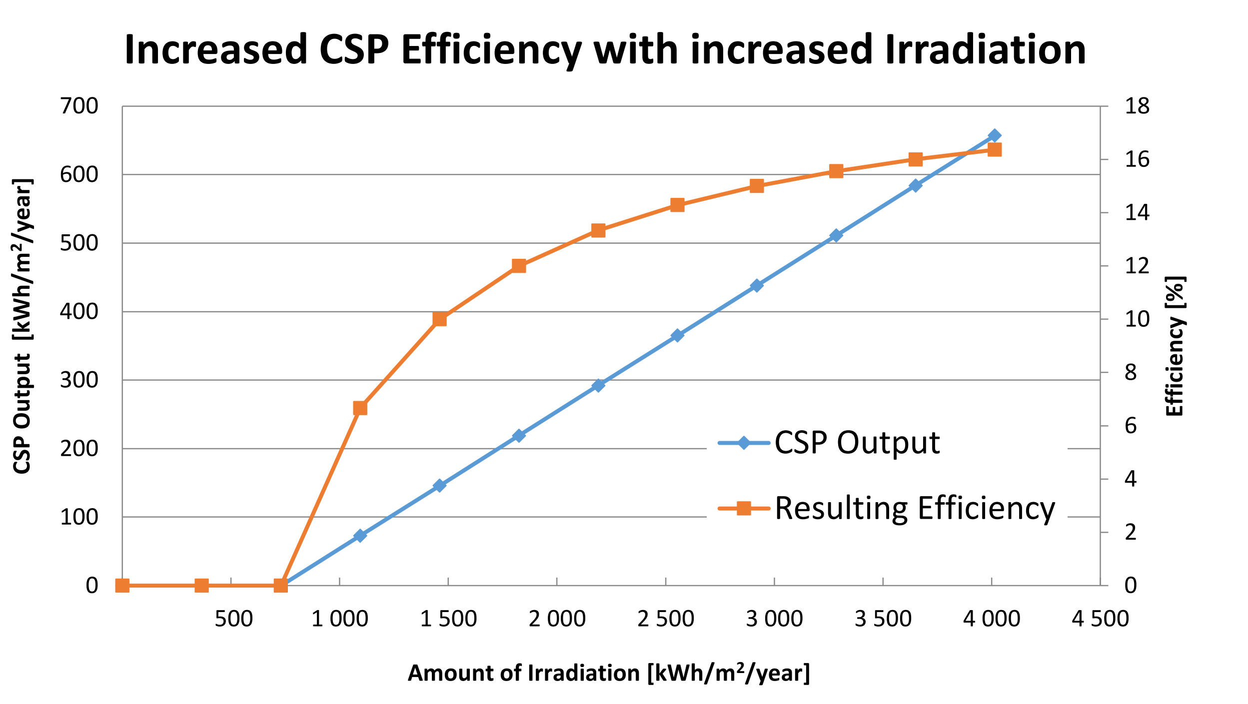
[9] *In this analysis we focus on conventional high-temperature CSP systems.*

CSP Plant Efficiency is given as a function of irradiation as presented in Figure 6. In our analysis different efficiency values were considered depending on the amount of irradiation received at a specific location. Areas with irradiation values of less than 1 800 kW/m²/year were not considered in the analysis for CSP production. Correspondingly, efficiency values start at approximately 12% (for irradiation values of 1 800 kW/m²/year) and increase to a maximum of approximately 16% (for irradiation values of 4 000 kW/m²/year and above) (IEA 2010; ETSAP & IRENA 2013). As in the case for solar PV, transmission and distribution efficiency values were not part of the analysis but should be included in a further investigation of technical potentials.

Equation 2: Basic formula for the development of technical solar CSP potential

Equation:	Resource Availability	x	CSP plant Efficiency	/	Spacing Factor	x	Available Area	=	Technical Potential
Units:	[kWh/m²/year]		[%]		[-]		[km²]		[GWh/year]
Example Values:	2 500		14 (function of irradiation values)		7.5		100		4 667

Figure 6: CSP efficiency in relation to the amount of irradiation received



Source: own calculation based on (IEA 2010, Figure 1)

Spacing Factor, or alternatively the GCR, is used to estimate the actual land use (ground areas) compared to the area of the actual panels (for PV) or mirrors (for CSP). An average factor for CSP installation lies in the order of 5-10 (meaning that the ground area needed is 5-10 times higher than the actual area that "collects" solar radiation (see also (IFC 2012)). Extra factors are relevant when considering CSP and include specific geometry of the solar collectors as well as maintenance and cleaning facilities, thermodynamic components and cooling, or even access road systems. As an approximate value we use 7.5 in our calculations.

Available Area is equal to the area calculated in the GIS analysis, taking into account exclusion zones and areas without sufficient resource (less than 1800 kW/m^2/year).

3.3 Wind energy

For wind energy, the calculation of the technical potential is complex due to the fact that the resources differ considerably over the area of an entire country. Nevertheless, an approximation can be made using the annual average wind speed of a region, as there is an established relationship between the wind speed and the average full-load hours (or the capacity factor) of a wind turbine (Hoogwijk *et al.* 2004). As different turbines yield different values for production at different wind speeds, we chose two different wind turbine models and respective manufacturer data to develop realistic load/power curves.

The turbines considered for this study were the ENERCON E82 and the Vestas V80, available on the market with well-known power characteristics. Both have a rotor of 80m diameter sitting on a hub at 80m height and with a rated capacity of 2MW.

As indicated in the "Wind Data" section in Appendix D, we used GIS data with wind speed measurements at 80m height. GIS maps were generated representing the geographic distribution of different potential wind power suitability categories, excluding all areas with average wind speeds of less than 4.5m/s.

Calculating the capacity factors relative to the wind speed categories is performed using the standard Rayleigh distribution method (with standard values for the shape factor k as specific wind speed distribution information is only available at low resolution). Considering constructor values for turbine output for both ENERCON E82 and Vestas V80 (rated C_{MW} = 2 MW) with comparable cut-in, rated and cut-off wind speeds of approximately 4.5–12 m/s and 25 m/s), we calculate average output power values and extrapolate them to a more detailed wind speed scale using excel trendlines. These power values are then multiplied by the respective amount of time per year that wind speed is available to obtain corresponding energies. For a given average speed category, these yearly fractions are calculated for each possible wind speed using a corresponding Rayleigh distribution.[10] Taking shape and curve parameters along with the yearly average wind speed, the distribution returns the density probability function of the wind speeds that, when multiplied by 8 760 as the number of hours in the year, yields the time that the a specific wind speed is available in one year. Gross energy production is then obtained as the sum of the yearly fractions of wind speed, thus enabling the capacity factors for each average wind speed category to be calculated. In this calculation of the capacity factor, no further losses are included – the values should therefore be seen as theoretically achievable values.

After calculating the technically achievable extraction from the wind at a given wind speed, a second step is needed to calculate the overall technical potential of an area: within this step, the maximum number of wind turbines per given area is calculated (in other words, the potential installed capacity per area). A simple and valid approach is to consider minimum spacing requirements of wind turbines. When taking into account that wind turbines need to have a minimum distance of 5 rotor diameters (main wind direction) and 3 rotor diameters (secondary wind direction), the minimum space requirement of a turbine with 80m rotor length (the manufacturer example above needs an area of 5x80m multiplied with 3x80m) is 96 000m^2 or about 0.1 km^2, resulting in a potential of 10.4 wind turbines per km^2. Assuming an installed capacity of 1.8-2.0 MW per turbine, this results in a power density of 18.7—20.8 MW per km^2. These are rather theoretical values as the highest power densities today are in the range of 17 MW/km^2 (dense arrays in California) and 5-8 MW/km^2 (wind farms in Europe) (Hoogwijk *et al.* 2004; Christie & Bradley 2012). It needs to be mentioned that different specific spacing assumptions do have a great impact on results and need to be transparent to compare theoretical values with on-the-ground realities.

In a last step, the power density chosen is multiplied with the respective wind energy class (in other words, the specific capacity factors) for a country. Using this approach, we then transfer this potential installed capacity into total annual production (in terawatts – TWh).

[10] *Within this analysis only standard estimated wind distributions were used (e.g. all calculations are started from standard k factors, 2). A further study currently under development is the introduction of monthly wind fluctuation and general wind distribution pattern in Africa.*

3.4 Bioenergy

The following analysis will be based on assessing the spatial potential of cultivated energy crops. For this purpose the general suitability of land at country level was evaluated and translated into quantifiable indicators. The generic potential to produce biomass – NPP potential – is translated into agricultural production potentials of three selected bioenergy crops (sugarcane, Jatropha and soybean). The sugarcane production potential is further assessed in terms of ethanol production potentials. For the other two crops, a further quantitative analysis was not undertaken due to high uncertainties related to the further processing chain towards a resulting biodiesel product. While ethanol production will require large-scale facilities with relatively well known efficiencies and yields, soybean and Jatropha oils can also be produced on a small scale and with different technical equipment, resulting in varying efficiencies and a range of oils qualities. In this report it is not possible to capture these uncertainties in sufficient detail. This analysis will serve as an illustration of the usefulness of a GIS approach to assess bioenergy potentials – the evaluation of the three plants is by no means meant to be a complete bioenergy assessment of the continent.

Solid biomass as well as waste and biogas are furthermore not part of the analysis as they are not primarily space-dependent and thus not suited to an assessment using a GIS approach.

A number of studies have been undertaken to quantify the amount potential (global) biofuel production and associated greenhouse gas (GHG) emissions reductions (*e.g.* (Smeets *et al.* 2007; Smeets *et al.* 2004; Beringer *et al.* 2011; REN21 2012; Field *et al.* 2008; Popp *et al.* 2011)). A review of these studies reveals that potentials vary considerably depending on the boundary conditions and scenarios taken into account. A recent study reviewing bioenergy potential forecasts reveals a bandwidth of contribution to global primary energy from approximately 0 to 200 EJ in the time frame of 2020-2030 (UKERC 2011), while IRENA's latest assessment indicates 105-150 EJ by 2030 (IRENA, 2014). IRENA also commissioned a survey study on Africa's biomass potential (IRENA 2013), according to which the biomass potential in Africa is in the range of 0-21 EJ by 2020. While some studies take indirect land-use changes into account, others do not, leading to very different results regarding overall GHG emission reductions and environmental impact (IEA 2011; Fischer *et al.* 2010; IFPRI 2011; FAO 2008; IEF 2010; Howarth *et al.* 2009). If effects of indirect land-use changes are included in the respective analysis, the general GHG balance tends to strongly move into a more negative direction. In extreme situations this can lead to cases where the overall emissions induced through cultivation and land-use change are greater than the emissions of the substitute fossil fuel resource (*e.g.* through the destruction of land areas with high carbon storage values, such as native forests and peat lands) (IFPRI 2011), resulting in the fact that bioenergy production for the sole purpose of GHG emission savings becomes counterproductive in those cases.

Furthermore, FAO estimates that the global demand for food is expected to increase by 60% by 2050 (FAO *et al. 2012).* This increase needs to be achieved through higher yields and expansion of the agricultural area. While there is still scope to increase yields considerably in sub-Saharan Africa, an increase in the agricultural area for food production seems still unavoidable (Fischer *et al.* 2010; FAO *et al.* 2012; WFP n.d.; IFPRI 2011). This leads to likely land-use conflicts in the future, which can affect areas that are currently not needed or used for food production.

The authors of this study are aware of the complexities involved when estimating biofuel potentials and explicitly do not generally recommend the application of biofuels without considering local circumstances. Nevertheless the analysis will quantify the amount of biomass and specifically biofuel production on the African continent after taking into account a number of constraints, including land availability (*e.g.* the exclusion of current agricultural land for food production as well as forest areas) and climate conditions. The aim of this approach is to quantify the scale of the bioenergy potential and locate geographic areas which are specifically interesting or problematic with respect to biocrop cultivation.

Developing county-level scenarios is a future prerequisite to translate theoretical biofuel potentials into sustainable energy sources with minimum negative side-effects. The results prepared in this study will give an overview of the theoretical potentials at country level and will help prioritise (and possibly limit) the use of biomass and biofuel in countries with the highest theoretical potentials. The approach used is by no means a final analysis, since only three crops are investigated, which alone offer a variety of different uses – simple combustion technologies, use as transport fuel or an integrated use as an advanced biofuel. The results and numbers given in this report are to be used with caution: they are prone to a number of uncertainties which can only be addressed in more detailed and specific investigations.

After the NPP potential of biomass is defined, the potential for the production of three of the main sources of (liquid) biofuels is evaluated on a per-country basis. The potential to grow sugarcane, Jatropha and soybeans is quantified using again the Agro Ecological Zoning Model (GAEZ) (IIASA & FAO 2012; Fischer *et al.* 2011) and will serve as illustrative examples that are also applicable to other crops. The results presented are based on a number of crop-specific indicators. Using these indicators, areas that are potentially suitable for biofuel crop production are identified together with corresponding yields or production rates. The calculations undertaken furthermore assume an "intermediate-level input agriculture" defined as an improved agricultural management system (Fischer *et al.* 2011). Since low-input and subsistence farming are still predominant on the continent, this will require agricultural practices that give higher yields (including more mechanisation, fertilizer and herbicide use with respective side effects and a likely "negative" feedback in form of increased energy demand in the agricultural sector.

3.4.1 Sugarcane

The most important sugar crop used as ethanol feedstock is sugar cane, due to its high agronomic productivity and well-developed and efficient conversion technologies. In addition, modern sugar cane processing allows producers to be flexible in catering to both sugar and ethanol markets (Fischer *et al.* 2010). Where certain climatic parameters are met, sugarcane often proves to be one of the most economic biofuel crops. Nevertheless, sugarcane cultivation and processing require a large amount of water and are most economical in large-scale facilities, making this crop less suitable for smallholder farmers or in water-restricted areas.

Figure 7 gives a graphical presentation of yield potential of sugarcane. Clearly, the equatorial areas are most suited for cultivation; nevertheless after applying a restriction map, a large part of this area is excluded due to existing forests and already cultivated land areas.

Figure 7: Overview of the GAEZ results for the cultivation of sugar cane in Africa

	Rain-fed Sugarcane Potential	Irrigated Sugarcane Potential
Total land areas without restrictions		
Applying restriction maps (*e.g.* protected areas, forest areas and currently used agricultural land)		

Source: GAEZ data, modified by the authors

Note: For rain-fed and irrigated sugar cane on the total land and available land. White areas represent regions without significant potential for sugarcane, darkest green represents highest potential yields.

The GIS-based results from the GAEZ model are tabulated and calculated on a country-level basis. Table 14, Table 15, Table 16 and Table 17 (in Appendix C) show the detailed results for sugarcane on a country level.

In a last step, the presented yield[11] and cultivation area data are converted into fuel amounts. Conversion factors are taken from (FAO 2004; FAO n.d.; FAO 2008) and based on official FAO methodologies. Table 18 (in Appendix C) gives the results in million litres of ethanol on a per-country basis for a set of three scenarios (total overall land without restrictions, restricted land with rain-fed sugar cane and restricted land with irrigated sugarcane).

[11] *Yield for sugar cane is given in tons of sugar per hectare.*

3.4.2 Jatropha

Jatropha is a shrub that can be found in a number of African countries and is frequently used as a protective hedge or to delimit farming lots. The seeds and fruits from this plant are non-edible. However, seeds may contain up to 40% oil[12], which can be used to produce different products such as soap, medicine and candles, it can also be used in standard diesel engines. Jatropha is easy to cultivate in semi-arid areas and it can develop on poor soils, it is also resistant to droughts and pests. The plant has a fairly high growth rate and it is able to produce seeds in under a year, although it usually reaches full productivity until it is three to five years old. Jatropha can live up to 30-40 years and requires little maintenance. Two harvests per year are possible (UEMOA & The Rural Hub 2008).

[12] *Standard conversion factor for the production of vegetable oil from Jatropha seeds is 0.35, taking into account the density of biofuel from Jatropha (0.85g/cm^3) ((FAO n.d.).*

Though Jatropha can subsist with little water, irrigation and fertilizer increase the yields. Additionally, despite its abundance, none of the Jatropha species have been properly domesticated and, as a result, its productivity is highly variable. Further, the long-term impact of its large-scale use on soil quality and the environment is unknown. Previously, Jatropha was sometimes presented as a wonder crop, but (Fischer *et al.* 2010) warns, "Despite considerable investment and projects being undertaken in many countries, reliable scientific data on the agronomy of Jatropha are not available."

Concern is growing that plant yields in a number of countries where Jatropha was introduced as a source of biofuel are not satisfactory and have been greatly overestimated in previous literature. A recent study (FAO & IFAD 2010) shows the potential for Jatropha as a smallholder bioenergy crop but also emphasises the large variation of yields depending on water availability, soil content and management practices. The range of yields mentioned in the report ranges from 0.1-12 tons per hectare (tons/ha), with realistic yields of only 2-3 tons/ha in semi-arid areas.

Figure 8: Overview of the GAEZ results for the cultivation of Jatropha in Africa

	Total land areas without restrictions	**Applying restriction maps (*e.g.* protected areas, forest areas and currently used agricultural land)**
Potential map for rain-fed Jatropha cultivation		

Source: GAEZ, modified by the authors

Note: For rain-fed Jatropha on the total land and on available land after applying restriction criteria. White areas represent regions without significant potential for Jatropha, darkest green represents highest potential yields.

3.4.3 Soybean

The origins of soybean are found in Southeast Asia, but after a rapid increase in importance in the second half of the last century soybean has become a major global crop commodity (with North and South America being the main producers). Today soybean is cultivated on about 6% of the global agricultural land area and has become the single most important oilseed globally (John Hay n.d.). Its rapid significance is reflected by the fact that in the past decades soybean has had the largest increase in cultivated areas of all agricultural crops.

Soybean is characterised by its high oil and protein content, and its meal has become a significant and cheap source of protein for animal feeds and is used in many pre-packaged meals.

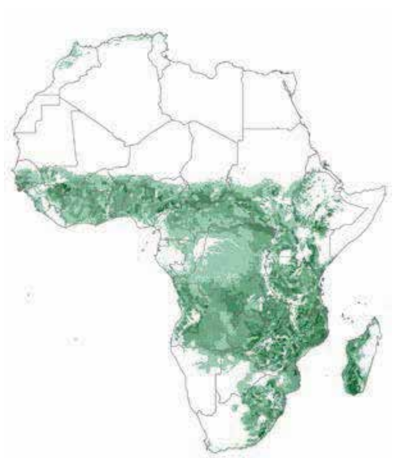
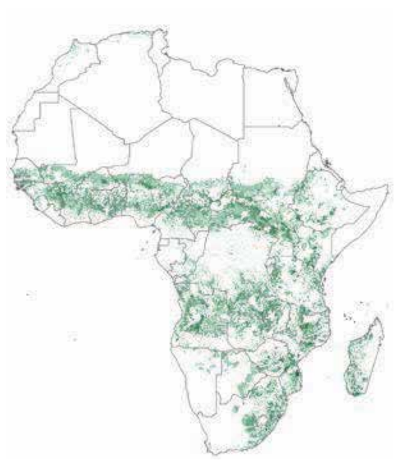
Although soybean is not a demanding crop in terms of soil needs, its cultivation can be associated with different problems: Cultivation (especially in North and South America) is often undertaken in form of extremely large-scale monocultures with respective negative effects on local biodiversity. Soybean cultivation has also lead to extensive changes in land use patterns, including deforestation (Barona *et al.* 2010; Malhi *et al.* 2008; Morton *et al.* 2006). These issues need to be taken seriously before advising large-scale soybean production on the African continent.

Today, soybean cultivation in Africa has not yet reached a significant scale, with South Africa being the largest producer on the continent (number 13 in the world, with 566 000 tons of production in 2010 according to FAO). Nevertheless, there is scope for soybean cultivation on the continent, with relatively large areas of the land being suitable for cultivation (see Figure 9).

Besides being a major food crop, soybean has significant potential to be used as a biofuel crop for biodiesel production. Although the energy content of the plant (soybeans contain approximately 18 to 20% oil) is smaller than in other oilseed crops such as canola (40%) or sunflower (43%), it has been found that the overall energy and GHG balance is comparable to other biodiesel crops and even favourable when compared to ethanol production from maize (Pimentel & Patzek 2005). The reason for this interesting result is the plant's ability to cope with poor soil conditions and the corresponding advantage of very low fertilizer (nitrogen) need for cultivation. This has a strong positive effect on the overall GHG and energy balance of the crop. General values for the energetic yield of soybean ranges from approximately 550-920 litres of biodiesel/ha (Pimentel & Patzek 2005; FAO 2004).

Figure 9 gives an overview of the cultivation potential of soybean in Africa and shows that generally more areas for soybean would be available then for Jatropha or sugarcane cultivation.

Figure 9: Overview of the GAEZ results for the cultivation of soybean in Africa

	Total land areas without restrictions	Applying restriction maps (e.g. protected areas, forest areas and currently used agricultural land)
Potential map for rain-fed soybean cultivation		

Source: GAEZ data, modified by the authors

Note: For rain-fed soybean cultivation on the total land area and on available land after applying restriction criteria. White areas represent regions without significant potential for Jatropha, darkest green represents highest potential yields.

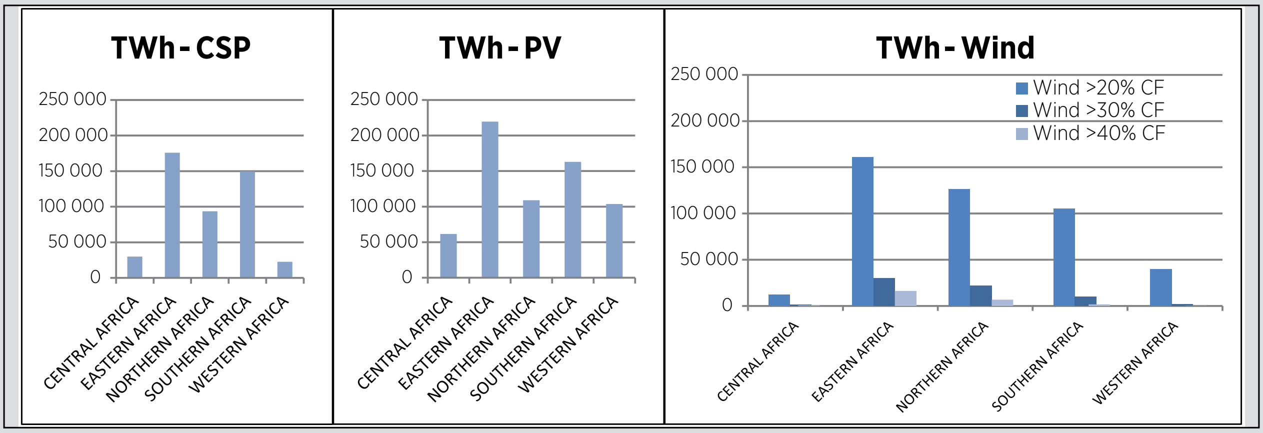
4. Discussion of the Results

4.1 Technical potential by region

Figure 10 gives an overview of first summarised CSP, PV and wind energy results based on African regions.

Detailed country-by-country results are presented in Appendix B.

Figure 10: Summary of RE potentials for different African regions



Note: Results are given in terawatt hours (TWh) per year. In the case of wind energy the total wind potential is separated by capacity factor (CF). A definition of the regions and their respective countries is found in Appendix E.

Total theoretical potentials in the whole Africa are estimated at around 470 Petawatt hours (PWh), 660 PWh, and 460 PWh for CSP, PV and wind respectively. For both CSP and PV, Eastern Africa has the highest potential (175 PWh and 220 PWh, respectively), followed by Southern Africa (150 PWh and 160 PWh respectively). Northern Africa has potential of about 100 PWh for both PV and CSP. Western Africa is endowed with good PV potential but limited CSP potential because of less direct irradiation and higher "solar fluctuations". Both effects are partly explained by distinctive climate and cloud cover in the West African region). Central Africa has relatively small potential for both CSP and PV compared with other regions. Countries with the highest PV and CSP potentials include Algeria, Egypt, Namibia, South Africa, Sudan and Tanzania.

Regarding wind energy potential, again Eastern Africa (170 PWh) presents the highest potential, followed by Northern Africa (130 PWh), Southern Africa (110 PWh), Western Africa (40 PWh), and Central Africa (10 PWh). It is important to note that most of the wind energy potential (around 85% of the total) corresponds to capacity factors between 20% and 30%, with potentials for projects with capacity factors over 30% being significantly lower. Algeria, Egypt, Somalia, South Africa and Sudan are among the countries with the highest wind energy potentials.

These potentials also show that although the five African regions have relatively similar areas, their overall potential of renewable energy sources is relatively different. This indicates that the regions need different strategies to develop their resources, but at the same time regions can benefit extensively from a better interconnection and increased information exchange of the five regional "power pools".

It should be noted that these potentials are purely geographic potentials, with no techno-economic evaluation undertaken, as explained in the "Methodology" section. Consequently, these resource potentials are subject to a significant reduction when economic parameters are applied.

Table 7 summarises the ranges of sugarcane-based bioethanol production potential. We analysed bioethanol potential in four categories: two yield categories – high yield (4 tons per hectare) and medium yield (2 tons per hectare) – and two water schemes – rain-fed and irrigated. Detailed country-by-country results are presented in Appendix C.

Table 7: Summary of sugarcane-based bioethanol production potential for different African regions

Region	Million litres			
	Rain-fed		Irrigated	
	>2 ton/ha	>4 ton/ha	>2 ton/ha	>4 ton/ha
Central Africa	41 901	1 172	91 734	18 472
Eastern Africa	21 715	5 200	157 932	83 272
Northern Africa	-	-	4 252	238
Southern Africa	21 325	9,085	172 344	100 226
Western Africa	10 652	218	58 617	7 616
TOTAL	95 593	15 675	484 879	209 825

Note: Production potential after applying restriction criteria.. A definition of the regions and their respective countries can be found in Appendix E.

When taking into account only the best suitable land for an efficient cultivation and yields of more than 4 tons of sugar per ha, the results show that the highest theoretical potentials for rain-fed sugarcane are in Southern Africa and Eastern Africa, followed by Central Africa and Western Africa, with Northern Africa showing no potential. Madagascar (5.8 billion litres), Uganda (3.7 billion litres), and Mozambique (3 billion litres) show the highest potential, making up for 80% of the total.[13] The values for irrigated sugarcane with yields higher than 2 tons per ha are shown as upper-limit values only.

These values are theoretical values and do not consider production and conversion inefficiencies. Such large-scale production targets would require a large-scale shift towards biofuels in the respective countries. This would affect current agricultural structures and practices to a large extent and would go hand in hand with increased energy, water and pesticide input, as well as highly increased levels of mechanisation. Even though the underlying analysis only considers marginal land as biofuel-growing areas, the large-scale expansion of biofuels will always need to be re-evaluated against the need for increased food production and should be treated with caution.

For the assessment of Jatropha and soybean potential, the size of land areas with yields greater than certain values was assessed. Potential yields were assessed, but they were not converted into fuel equivalent, due to high uncertainties and lack of information on the further conversion processes. Table 8 summarises the size of the land areas with yields greater than 2 tons per ha.

[13] *For comparison it can be stated that ethanol production in Brazil in 2007 was approximately 19 billion litres.*

Table 8: Summary of land areas for Jatropha and soybean crops with yields over 2 tons/ha

Region	Thousand ha	
	Jatropha	Soybean
	>2 tons/ha	>2 tons/ha
Central Africa	59	430
Eastern Africa	59	3 982
Northern Africa	-	-
Southern Africa	1 373	8 269
Western Africa	-	2 234
TOTAL	1 491	14 915

Note: Land areas after applying restriction criteria. A definition of the regions and their respective countries can be found in Appendix E.

Southern Africa is the region with the highest potential for Jatropha crops, followed by Eastern Africa and Central Africa. Northern Africa and Western Africa have virtually no potential for growing either crop. The countries with the highest potentials are Madagascar (723 000 ha) and Mozambique (649 000 ha), which account for 92% of the total available land area for Jatropha crops. Soybean crops show a significantly higher potential than Jatropha crops in all regions. Again, South Africa has the largest amount of available land area, followed by Eastern Africa, Northern Africa and Western Africa. Countries with the highest potentials include Mozambique (3.9 million ha), Madagascar (2.8 million ha), Kenya (1.5 million ha), Tanzania (1.2 million ha) and Nigeria (1.2 million ha).

At this point the authors want to emphasise again that the approach used is valid for a large region assessment only. Jatropha may in fact be a good example of a crop to be cultivated at small scale and in agricultural niches (*e.g.* waste water irrigation (Agricultural Research Center (ARC) 2008)) that can be very relevant in local circumstances. Such small-scale applications are not captured by the underlying approach.

It needs to be stated that using the NPP as a proxy for real plant growth is a valid approach; nevertheless it does not reflect the opportunity to diversify the biofuel crop selection according to a country's conditions. Optimizing land resources will include the selection of a suite of available biofuel crops harmonised with the existing climate and soil conditions. Therefore estimations based on one crop only have only limited validity.

4.2 Limitations and sources of uncertainty

The quality of data sources for GIS processing is of great concern, as the results strongly depend on the quality of data input. The fundamental issue with respect to data is *accuracy*. Accuracy is the closeness of results of observations to the true values or values accepted as being true. Keeping this in mind, it is critical that the spatial and attribute accuracy of all input layers is evaluated.

Within the applied process for the renewable energy assessment, data from a number of different sources with different spatial resolutions and different accuracies have been used (a list of data can be found in Appendix D). Even though all datasets used were harmonised in the process, it is still true that the quality of the final results depends on the map layers with the least quality and accuracy. Therefore it is important to understand the accuracy of each individual data source used and whether the data were validated with on- the-ground observations.

For our specific work, the spatial resolution played a critical role, as maps over large territories were used. It is true that data can always be generalised to a smaller scale – but the resulting values will nevertheless inherit errors as local irregularities and specificities are not captured and information is "lost" in the process. It is therefore important that the resource maps used be validated to ensure that map values correspond to real-life measurements (*e.g.* irradiation, wind speed). A possible error between the mapped values and on-the-ground observations (arising from wrong interpretation or wrong geographic translation) is directly imported into the approach without any correction possibility and therefore may lead to substantial unaccounted-for errors.

As mainly large-region data (maps of the whole continent) have been used in the analysis, it cannot be assumed that a thorough validation was possible simply due to the lack of validation points. Within our approach two main methodological sources of influence on the results can be characterised and should be kept in mind: data and processing of the resource maps (solar irradiation and wind speed) and the development of restriction areas and zones. Using this approach for small areas (*e.g.* at a country or regional level) with more detailed maps will eliminate some of the uncertainties inherited in our "continental approach" and therefore will yield more accurate results.

The restriction areas are developed from publically available and largely validated GIS maps. Nevertheless the creation of the exclusion zones is prone to inaccuracies due to the different spatial resolutions of the input layers, meaning that "coarse" input layers supersede and override the detail of high-resolution restriction maps. This leads to a loss of detail and favours coarse restriction areas, which do not correspond with reality. All of the above has a direct influence on results and therefore needs to be made transparent in the data development and production of results.

5. Summary and Outlook

As the results are complex, they have been compiled in Appendices A, B and C in form of tables and overview maps. Appendix D contains a detailed description of all underlying data sources.

The very first part of Appendix A gives an overview of the potentials for the different African regions, showing that Eastern and Northern Africa has the largest potential in both solar and wind applications while central Africa has the lowest potential. Additionally some countries in Southern Africa (*e.g.* Mozambique, Namibia, South Africa) show great potential for different RETs. The country-level results (available Appendices A, B, and C) represent the resource potentials for CSP, PV, wind power and bioenergy based on the available land areas as described under the Methodology section of this report. The results are purely geographic potentials which need refinement for further investigation of technical feasibility and economic potential at national or subnational level. The results presented in the tables are especially interesting for a number of reasons: firstly, the size of a country naturally has an influence on the expected potential; secondly, the analysis also shows that although the five African regions have relatively similar areas their overall potential of renewable energy sources is very different. This indicates that the regions need different strategies to develop their resources, but at the same time regions could extensively benefit from a better interconnection of the five regional "power pools".

In the case of bioenergy, clearly the equatorial region offers greatest potentials for biofuels from cultivated energy crops, due to its climatic conditions and the associated growing conditions for many plants. At the same time this poses a large threat as this is the region with the largest remaining forest area and connected ecosystems services and biodiversity.

Even though our analysis should be seen as a "first attempt", the results yield interesting insights as available land areas for large-scale biofuel application are significantly reduced if "restricted areas" are considered. A modified GIS approach can easily be adapted to local needs and can be refined with higher-resolution local data. As the underlying report only considers three selected biocrops representing a very limited range of bioenergy technologies, the results should be taken with extreme caution, as other specific technologies (such as advanced biofuels or biogas) may have larger potentials in many of the investigated countries.

Furthermore, the food situation on the continent is still precarious, making large-scale biofuel application a complex and region-specific matter. Potential expansion areas for agriculture (to accommodate biofuel crops) are often situated in climatically fragile areas which in the future may be especially affected (positively or negatively) by climate change effects, making quantifiable assumptions for the future even more complex.

We are aware that the approach used leaves scope for extensive refinement and introduction of further classification, finer resolution and further parameterisation. Nevertheless, our approach gives an initial indication of the renewable energy potential in Africa using uniform methodologies to provide initial national and regional estimates.

The methodology used is very sensitive to given input parameters as well as selected restriction zones and suitability classes. As highlighted in the report, the results of a GIS analysis very much depend on the quality of the layers employed. For this reason, all used layers are appended with their source in Appendix D.

As a possible next step, the assessment of additional renewable energy resources could be conducted. This would include the assessment of additional bioenergy potentials as well as hydropower potentials. Moreover, the assessment of wind energy potential could be refined using new datasets to investigate wind density distributions and seasonal variation. For CSP the introduction of water availability as a constraining factor should be investigated, as this can have a large impact on the economics of the CSP technology.

The results presented in this report and additional analyses based on alternative GIS layers will be made publicly available and accessible on IRENA's Global Atlas website (http://globalatlas.irena.org) as well as on the KTH-dESA website (http://www.desa.kth.se).

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Appendix A – Results Tables[14] (CSP, PV, Wind)

Table 9: Summary of renewable energy potentials in different African regions[15]

		CSP	PV	Wind			
		Overall sum (taking into account all suitable areas)	Overall sum (taking into account all suitable areas)	Overall sum (Total theoretical potential using all available areas)	All areas with wind turbine CF greater than 20%	All areas with wind turbine CF greater than 30%	All areas with wind turbine CF greater than 40%
Region	**Total Area [km2]**	**TWh/year**	**TWh/year**	**TWh/year**	**TWh/year**	**TWh/year**	**TWh/year**
Central Africa	**5 317 718**	**29 909**	**61 643**	**12 395**	**12 395**	**1.576,7**	**578,3**
Eastern Africa	**6 225 847**	**175 777**	**219 481**	**165 873**	**165 873**	**30.860,0**	**16.580,5**
Northern Africa	**6 784 934**	**93 544**	**109 033**	**130 316**	**130 316**	**22.500,9**	**6.919,9**
Southern Africa	**6 555 480**	**149 610**	**162 817**	**108 235**	**108 235**	**10.011,1**	**1.707,3**
Western Africa	**5 006 014**	**22 747**	**103 754**	**40 846**	**40 846**	**1.692,2**	**58,8**

15 *CF = Capacity factor. Northern Africa includes data from Western Sahara. The use of Western Sahara follows United Nations practices.*

14 *As exclusion areas the above described methodology is used. A definition of the country groups / regions can be found in Appendix E.*

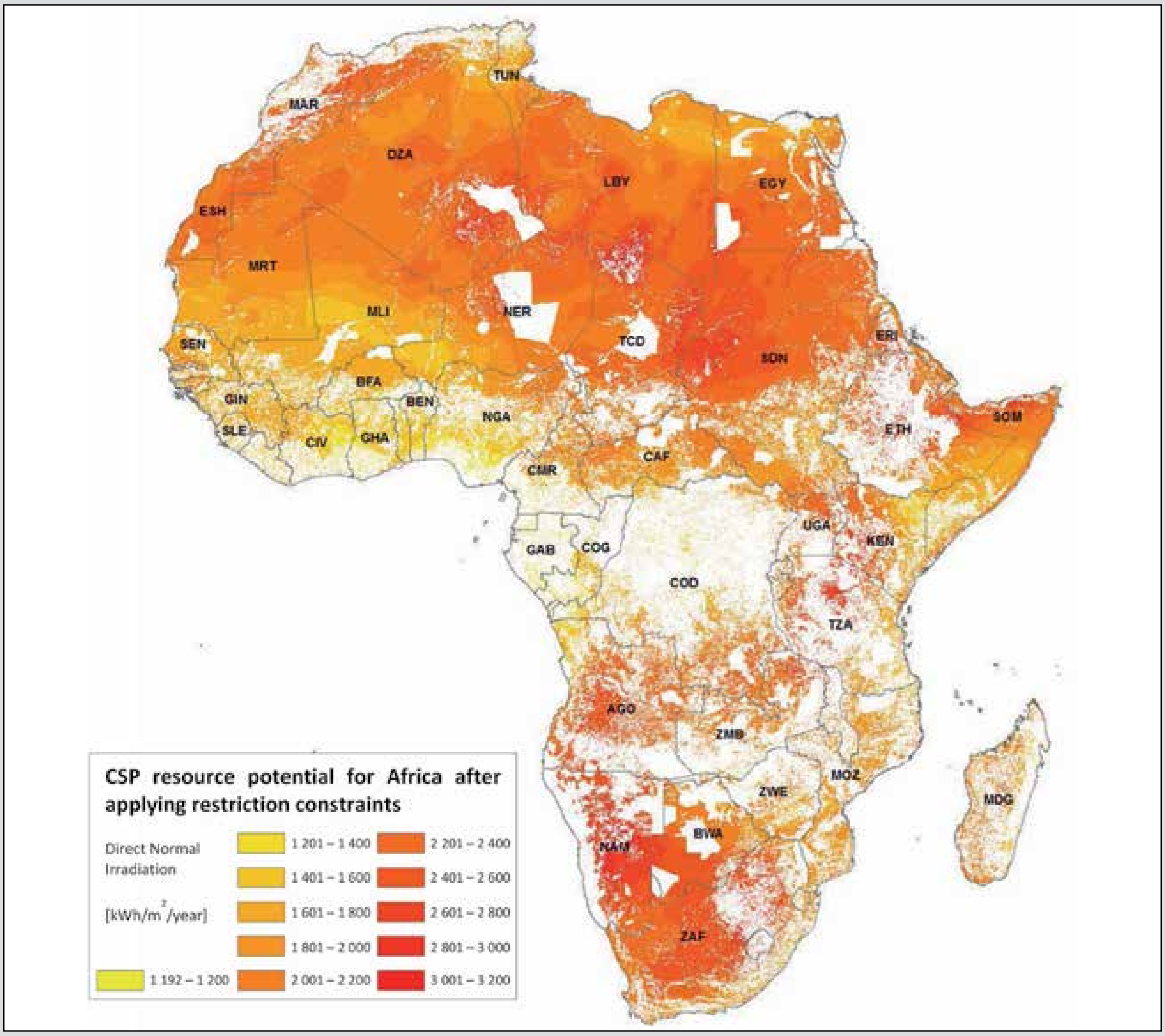
Table 10: Results by country for PV, CSP and wind energy

				CSP	PV	WIND		
				Overall sum (taking into account all suitable areas)	Overall sum (taking into account all suitable areas)	All areas with wind turbine CF greater than 20%	All areas with wind turbine CF greater than 30%	All areas with wind turbine CF greater than 40%
Country Name	**Short**	**Region**	**Total Area [km²]**	**TWh/year**	**TWh/year**	**TWh/year**	**TWh/year**	**TWh/year**
Algeria	DZA	NA	2 316 559	26 530	27 904	30 155	2.535,9	153,4
Angola	AGO	SA	1 247 357	9 786	13 319	202	-	-
Benin	BEN	WA	115 543	-	3 898	405	-	-
Botswana	BWA	SA	578 084	13 070	13 764	9 793	302,9	-
Burkina Faso	BFA	WA	273 367	-	7 742	4 154	7,5	-
Burundi	BDI	EA	26 949	786	888	-	-	-
Cameroon	CMR	CA	466 295	3 706	10 105	979	15,9	-
Central African Republic	CAF	CA	620 200	3 471	5 284	79	-	-
Chad	TCD	CA	1 269 961	10 284	10 506	9 165	1.519,4	578,3
Congo	COG	CA	341 574	2	6 778	-	-	-
Congo (Democratic Republic of the)	COD	CA	2 327 986	12 439	22 862	2 173	41,4	-
Côte d'Ivoire	CIV	WA	321 882	221	10 325	430	-	-
Djibouti	DJI	EA	21 679	852	947	934	149,1	77,3
Egypt	EGY	NA	982 446	26 605	32 218	36 601	6.185,0	572,9
Equatorial Guinea	GNQ	CA	26 987	-	706	-	-	-
Eritrea	ERI	EA	122 098	4 349	4 775	3 154	412,4	129,1
Ethiopia	ETH	EA	1 127 582	22 959	27 154	14 838	3.002,1	1.981,0
Gabon	GAB	CA	264 715	6	5 402	-	-	-
Gambia	GMB	WA	10 797	316	474	173	1,3	-
Ghana	GHA	WA	238 761	229	7 644	606	2,4	-
Guinea	GIN	WA	244 871	467	5 204	2	-	-
Guinea-Bissau	GNB	WA	33 974	906	1 493	124	-	-

				CSP	PV	WIND		
				Overall sum (taking into account all suit-able areas)	Overall sum (taking into account all suit-able areas)	All areas with wind turbine CF greater than 20%	All areas with wind tubine CF greater than 30 %	All areas with wind tubine CF greater than 40 %
Country Name	**Short**	**Region**	**Total Area [km²]**	**TWh/year**	**TWh/year**	**TWh/year**	**TWh/year**	**TWh/year**
Kenya	KEN	EA	582 253	15 399	23 046	22 476	4.446,4	1.739,6
Lesotho	LSO	SA	30 454	1 122	938	599	40,1	3,7
Liberia	LBR	WA	95 877	-	667	-	-	-
Libya	LBY	NA	1 616 869	11 823	13 979	21 649	5.149,5	1.079,5
Madagascar	MDG	SA	591 575	3 194	4 987	2 617	281,8	29,1
Malawi	MWI	SA	118 062	4 474	5 210	1 986	262,1	42,4
Mali	MLI	WA	1 251 574	-	7 906	1 923	-	-
Mauritania	MRT	NA	1 040 738	4 988	7 990	11 822	2.940,5	1.337,8
Morocco	MAR	NA	406 318	15 127	15 155	11 297	1.458,8	851,0
Mozambique	MOZ	SA	786 096	16 851	22 024	10 805	395,9	5,2
Namibia	NAM	SA	824 205	29 716	26 183	15 196	497,0	4,9
Niger	NER	WA	1 183 766	8 829	15 669	14 628	1.262,0	55,8
Nigeria	NGA	WA	909 481	10 045	32 456	12 867	95,3	-
Rwanda	RWA	EA	25 206	789	892	-	-	-
Senegal	SEN	WA	196 761	1 537	7 519	5 454	323,6	3,0
Sierra Leone	SLE	WA	72 322	197	1 499	-	-	-
Somalia	SOM	EA	633 217	13 156	25 687	43 539	10.616,4	8.893,3
South Africa	ZAF	SA	1 220 394	43 275	42 243	41 195	6.076,3	1.559,1
Sudan	SDN	EA	2 503 827	77 422	87 817	61 661	9.837,8	2.947,1
Swaziland	SWZ	SA	17 289	559	572	476	9,7	-
Tanzania	TZA	EA	941 758	31 482	38 804	18 456	2.295,2	789,2
Togo	TGO	WA	57 038	-	1 257	79	-	-
Tunisia	TUN	NA	155 176	2 045	4 645	6 842	1.244,0	226,5
Uganda	UGA	EA	241 278	8 582	9 470	815	100,7	23,8
Zambia	ZMB	SA	751 315	15 691	17 894	13 229	1.145,0	15,6
Zimbabwe	ZWE	SA	390 649	11 874	15 684	12 137	1.000,3	47,3

Appendix B – Main Results Maps (Solar and Wind)

Figure 11: CSP resource potential for Africa after applying restriction criteria



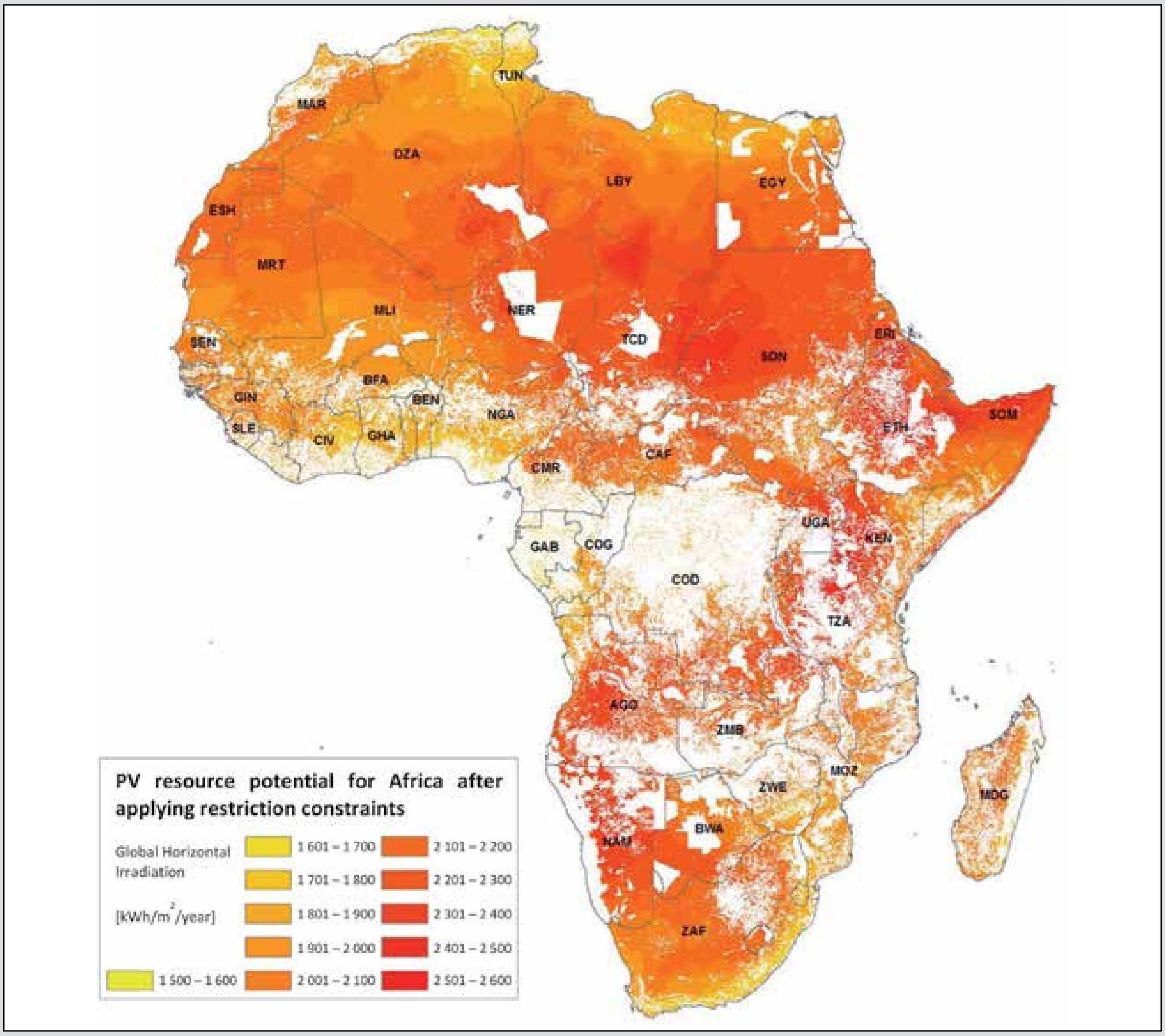
Source: own illustration

Table 11: Areas associated with different suitability classes (CSP)

Name	Short	Total Area [km²]	Exclusion Area [km²]	CSP (Potential Categories) - Associated Areas Direct Normal Irradiation [kWh/m2/year] 1 800 [km²]	1 800 - 2 000 [km²]	2 000 - 2 500 [km²]	2 500 -3 000 [km²]
Algeria	DZA	2 316 559	1 569 600	62 797	169 312	484 798	30 051
Angola	AGO	1 247 357	935 615	75 281	22 857	182 065	31 539
Benin	BEN	115 543	4 195	111 348	-	-	-
Botswana	BWA	578 084	265 409	-	55 910	187 435	69 329
Burkina Faso	BFA	273 367	52 167	221 200	-	-	-
Burundi	BDI	26 949	7 212	-	1 477	18 260	-
Cameroon	CMR	466 295	211 601	152 393	46 804	55 496	-
Central African Republic	CAF	620 200	501 823	21 675	47 670	49 031	-
Chad	TCD	1 269 961	1 036 490	-	-	171 617	61 854
Congo	COG	341 574	148 048	193 464	62	-	-
Congo (Democratic Republic of the)	COD	2 327 986	1 790 372	192 684	163 850	181 080	-
Côte d'Ivoire	CIV	321 882	30 411	284 425	6 912	135	-
Djibouti	DJI	21 679	643	-	-	21 036	-
Egypt	EGY	982 446	220 611	80 057	107 853	573 924	-
Equatorial Guinea	GNQ	26 987	6 828	20 159	-	-	-
Eritrea	ERI	122 098	15 988	-	6 116	91 887	8 107
Ethiopia	ETH	1 127 582	522 231	73 340	95 134	265 129	171 747
Gabon	GAB	264 715	110 504	154 012	199	-	-
Gambia	GMB	10 797	257	656	9 036	847	-
Ghana	GHA	238 761	23 071	208 449	6 837	404	-
Guinea	GIN	244 871	109 061	121 016	14 118	676	-
Guinea-Bissau	GNB	33 974	806	5 155	24 510	3 503	-

Name	Short	Total Area [km²]	Exclusion Area [km²]	CSP (Potential Categories) - Associated Areas Direct Normal Irradiation [kWh/m2/year] 1 800 [km²]	1 800 - 2 000 [km²]	2 000 - 2 500 [km²]	2 500 -3 000 [km²]
Kenya	KEN	582 253	57 053	143 241	99 045	219 119	63 795
Lesotho	LSO	30 454	9 608	-	-	141	20 704
Liberia	LBR	95 877	76 813	19 064	-	-	-
Libya	LBY	1 616 869	1 241 042	59 722	104 835	211 269	-
Madagascar	MDG	591 575	470 590	38 022	17 782	65 182	-
Malawi	MWI	118 062	2 291	-	23 006	92 765	-
Mali	MLI	1 251 574	1 025 676	225 898	-	-	-
Mauritania	MRT	1 040 738	851 352	60 027	26 883	102 476	-
Morocco	MAR	406 318	36 610	-	6 907	346 523	16 278
Mozambique	MOZ	786 096	263 635	25 823	349 389	147 250	-
Namibia	NAM	824 205	242 215	-	1 221	121 330	459 439
Niger	NER	1 183 766	809 033	148 049	61 841	147 961	16 882
Nigeria	NGA	909 481	72 591	555 606	144 220	137 064	-
Rwanda	RWA	25 206	5 382	-	1 489	18 335	-
Senegal	SEN	196 761	15 356	133 275	44 135	3 995	-
Sierra Leone	SLE	72 322	31 202	34 796	6 321	3	-
Somalia	SOM	633 217	27 901	278 645	47 805	251 046	27 820
South Africa	ZAF	1 220 394	202 816	13 530	171 651	517 904	314 494
Sudan	SDN	2 503 827	546 891	21 592	341 756	1 426 986	166 611
Swaziland	SWZ	17 289	1 049	-	10 595	5 645	-
Tanzania	TZA	941 758	80 565	126 621	135 218	375 832	223 523
Togo	TGO	57 038	21 187	35 851	-	-	-
Tunisia	TUN	155 176	22 464	72 386	42 656	17 670	-
Uganda	UGA	241 278	30 828	-	1 742	203 108	5 600
Zambia	ZMB	751 315	353 437	-	47 450	348 952	1 474
Zimbabwe	ZWE	390 649	10 177	41 479	198 668	140 324	-

Figure 12: PV resource potential for Africa after applying restriction criteria



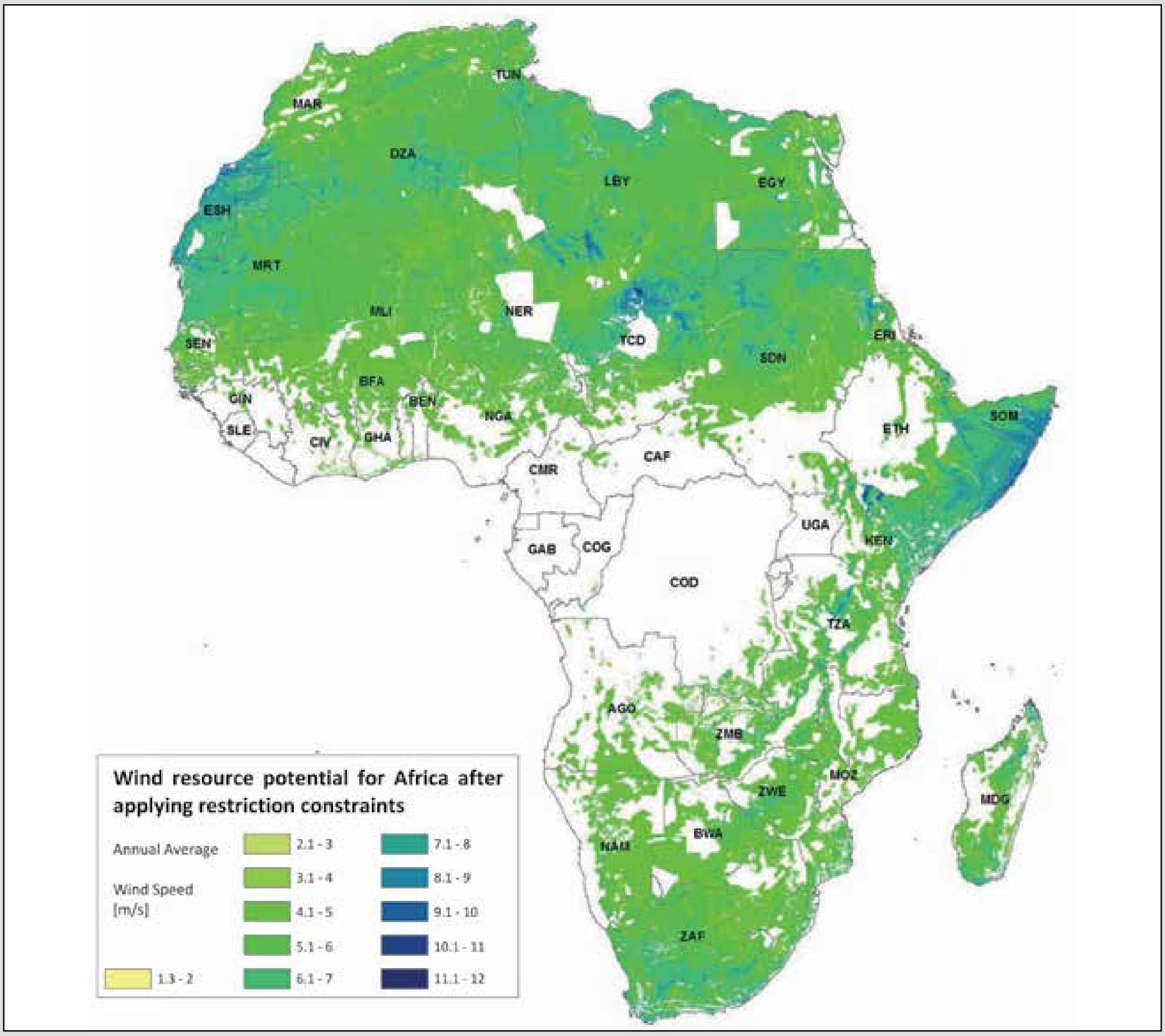
Source: own illustration

Table 12: Areas associated with different suitability classes (PV)

Name	Short	Total Area [km²]	Exclusion Area [km²]	PV (Potential Categories) Global Horizontal Irradiation [kWh/m2/year] 1 500 - 2 000 [km²]	2 000 - 2 500 [km²]	2 500 - 3 000 [km²]
Algeria	DZA	2 316 559	1 569 600	570 894	176 064	-
Angola	AGO	1 247 357	935 615	70 958	240 784	-
Benin	BEN	115 543	4 195	111 216	132	-
Botswana	BWA	578 084	265 409	30 655	282 020	-
Burkina Faso	BFA	273 367	52 167	221 200	-	-
Burundi	BDI	26 949	7 212	-	19 737	-
Cameroon	CMR	466 295	211 601	135 617	119 076	-
Central African Republic	CAF	620 200	501 823	4 315	114 061	-
Chad	TCD	1 269 961	1 036 490	-	233 472	-
Congo	COG	341 574	148 048	193 020	505	-
Congo (Democratic Republic of the)	COD	2 327 986	1 790 372	133 049	404 565	-
Côte d'Ivoire	CIV	321 882	30 411	279 160	12 312	-
Djibouti	DJI	21 679	643	-	21 036	-
Egypt	EGY	982 446	220 611	206 412	555 423	-
Equatorial Guinea	GNQ	26 987	6 828	20 159	-	-
Eritrea	ERI	122 098	15 988	-	106 110	-
Ethiopia	ETH	1 127 582	522 231	12 883	588 252	4 216
Gabon	GAB	264 715	110 504	153 793	419	-
Gambia	GMB	10 797	257	-	10 540	-
Ghana	GHA	238 761	23 071	206 176	9 514	-
Guinea	GIN	244 871	109 061	90 749	45 062	-
Guinea-Bissau	GNB	33 974	806	-	33 168	-

Name	Short	Total Area [km²]	Exclusion Area [km²]	PV (Potential Categories) Global Horizontal Irradiation [kWh/m2/year] 1 500 - 2 000 [km²]	2 000 - 2 500 [km²]	2 500 - 3 000 [km²]
Kenya	KEN	582 253	57 053	66 369	451 266	7 565
Lesotho	LSO	30 454	9 608	-	20 846	-
Liberia	LBR	95 877	76 813	19 064	-	-
Libya	LBY	1 616 869	1 241 042	293 308	82 519	-
Madagascar	MDG	591 575	470 590	45 781	75 204	-
Malawi	MWI	118 062	2 291	-	115 771	-
Mali	MLI	1 251 574	1 025 676	225 898	-	-
Mauritania	MRT	1 040 738	851 352	53 252	136 134	-
Morocco	MAR	406 318	36 610	148 136	221 572	-
Mozambique	MOZ	786 096	263 635	148 725	373 737	-
Namibia	NAM	824 205	242 215	621	581 369	-
Niger	NER	1 183 766	809 033	119 399	255 334	-
Nigeria	NGA	909 481	72 591	520 392	316 499	-
Rwanda	RWA	25 206	5 382	-	19 824	-
Senegal	SEN	196 761	15 356	64 466	116 939	-
Sierra Leone	SLE	72 322	31 202	35 144	5 976	-
Somalia	SOM	633 217	27 901	155 202	450 114	-
South Africa	ZAF	1 220 394	202 816	354 803	662 776	-
Sudan	SDN	2 503 827	546 891	24 504	1 932 441	-
Swaziland	SWZ	17 289	1 049	15 904	335	-
Tanzania	TZA	941 758	80 565	5 501	845 122	10 570
Togo	TGO	57 038	21 187	35 619	232	-
Tunisia	TUN	155 176	22 464	132 712	-	-
Uganda	UGA	241 278	30 828	-	210 450	-
Zambia	ZMB	751 315	353 437	1 001	396 876	-
Zimbabwe	ZWE	390 649	10 177	143 747	236 725	-

Figure 13: Wind resource potential for Africa after applying restriction criteria



Source: own illustration

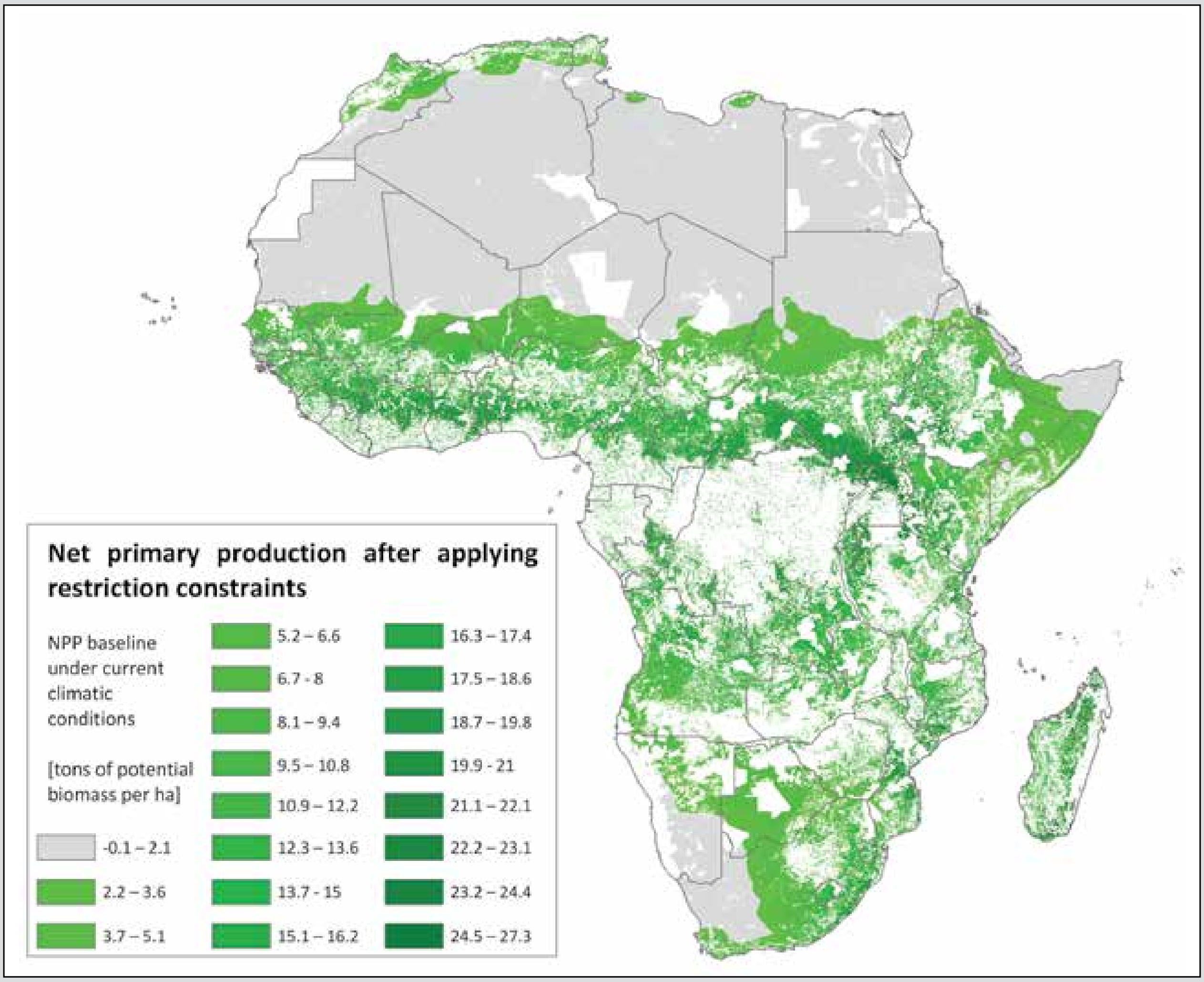
Table 13: Areas associated with different suitability classes (Wind)

Areas restricted to 10-200km around urban centers:			Wind (Potential Categories) Yearly Wind Speed Average [m/s]								
		Total	Exclusion								
Name	Short	Area	Generally	< 4m/s	< 5m/s	5-6 m/s	6-7 m/s	7-8 m/s	8 -9 m/s	9 -10 m/s	10-11 m/s
		[km²]	[km²]	[km²]	[km²]	[km²]	[km²]	[km²]	[km²]	[km²]	[km²]
Algeria	DZA	2 316 559	1 569 600	-	56 577	512 395	169 539	8 449			
Angola	AGO	1 247 357	935 615	147 060	159 520	5 163	-	-	-	-	-
Benin	BEN	115 543	4 195	14 245	86 742	10 361	-	-	-	-	-
Botswana	BWA	578 084	265 409	12	71 389	219 722	21 552	-	-	-	-
Burkina Faso	BFA	273 367	52 167	738	114 335	105 591	536	-	-	-	-
Burundi	BDI	26 949	7 212	13 765	5 972	-	-	-	-	-	-
Cameroon	CMR	466 295	211 601	193 285	36 851	23 424	1 133	-	-	-	-
Central African Republic	CAF	620 200	501 823	67 318	49 046	2 013	-	-	-	-	-
Chad	TCD	1 269 961	1 036 490	3 942	53 147	79 055	66 968	23 846	5 407	1 107	-
Congo	COG	341 574	148 048	143 392	50 134	-	-	-	-	-	-
Congo (Democratic Republic of the)	COD	2 327 986	1 790 371	374 667	108 603	51 402	2 943	-	-	-	-
Côte d'Ivoire	CIV	321 882	30 411	50 467	229 982	11 023	-	-	-	-	-
Djibouti	DJI	21 679	643	-	3 035	8 656	5 108	4 140	98	-	-
Egypt	EGY	982 446	220 611	-	27 218	303 703	399 362	31 552	-	-	-
Equatorial Guinea	GNQ	26 987	6 828	17 568	2 591		-	-	-	-	-
Eritrea	ERI	122 098	15 988	3 769	36 629	38 524	20 155	6 641	392	-	-
Ethiopia	ETH	1 127 582	522 231	215 300	137 421	72 442	72 662	99 912	7 294	321	-
Gabon	GAB	264 715	110 504	146 314	7 897	-	-	-	-	-	-
Gambia	GMB	10 797	257	-	6 153	4 291	96	-	-	-	-
Ghana	GHA	238 761	23 071	26 821	173 434	15 265	170	-	-	-	-
Guinea	GIN	244 871	109 061	49 222	86 534	54	-	-	-	-	-
Guinea-Bissau	GNB	33 974	806	-	29 990	3 178	-	-	-	-	-

Areas restricted to 10-200km around urban centers:			Wind (Potential Categories) Yearly Wind Speed Average [m/s]								
		Total	Exclusion								
Name	Short	Area	Generally	< 4m/s	< 5m/s	5-6 m/s	6-7 m/s	7-8 m/s	8 -9 m/s	9 -10 m/s	10-11 m/s
		[km²]	[km²]	[km²]	[km²]	[km²]	[km²]	[km²]	[km²]	[km²]	[km²]
Kenya	KEN	582 253	57 163	44 880	75 453	120 110	192 618	78 964	7 375	4 490	1 202
Lesotho	LSO	30 454	9 608	237	6 595	11 219	2 590	204	-	-	-
Liberia	LBR	95 877	76 813	18 306	759	-	-	-	-	-	-
Libya	LBY	1 616 869	1 241 042	-	-	26 913	289 631	58 446	836	-	-
Madagascar	MDG	591 575	470 590	12 511	50 736	38 153	17 980	1 604	-	-	-
Malawi	MWI	118 062	2 291	37 041	36 750	24 010	15 636	2 334	-	-	-
Mali	MLI	1 251 574	1 025 676	365	176 291	49 241	-	-	-	-	-
Mauritania	MRT	1 040 738	851 352	-	1 353	1 551	114 047	66 306	5 994	135	-
Morocco	MAR	406 318	36 610	11 332	131 678	139 847	43 254	28 348	13 887	1 363	-
Mozambique	MOZ	786 096	263 635	30 033	228 222	236 117	27 805	285	-	-	-
Namibia	NAM	824 205	242 215	14	208 505	338 186	35 015	271	-	-	-
Niger	NER	1 183 766	809 033	-	40 526	245 298	85 835	3 074	-	-	-
Nigeria	NGA	909 481	72 591	188 086	322 320	319 701	6 783	-	-	-	-
Rwanda	RWA	25 206	5 382	15 310	4 514	-	-	-	-	-	-
Senegal	SEN	196 761	15 356	-	51 913	106 512	22 815	164	-	-	-
Sierra Leone	SLE	72 322	31 202	36 518	4 602	-	-	-	-	-	-
Somalia	SOM	633 217	27 901	-	7 070	27 493	122 616	264 747	153 725	29 664	-
South Africa	ZAF	1 220 394	202 816	23 190	155 364	432 467	321 454	81 340	3 726	38	-
Sudan	SDN	2 503 827	546 891	198 444	535 841	571 245	490 354	154 814	6 242	-	-
Swaziland	SWZ	17 289	1 049	-	4 347	11 203	690	-	-	-	-
Tanzania	TZA	941 758	80 565	151 616	322 860	237 481	107 172	35 021	7 042	-	-
Togo	TGO	57 038	21 187	12 924	20 910	2 017	-	-	-	-	-
Tunisia	TUN	155 176	22 464	-	54	47 780	72 403	12 475	-	-	-
Uganda	UGA	241 278	30 828	142 469	50 652	10 549	5 468	1 312	-	-	-
Zambia	ZMB	751 315	353 437	33 808	61 376	221 464	80 369	860	-	-	-
Zimbabwe	ZWE	390 649	10 177	17 387	84 340	208 322	67 819	2 603	-	-	-

Appendix C –
Results Tables (Bioenergy)

Figure 14: Net primary production after applying restriction criteria



Source: own illustration

Table 14: Total land areas without applying any restriction criteria and their potential (rain-fed) sugarcane yield in tons of sugar/ha

Country	Area	Restricted land	Yield values (tons/ha) 0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8		Land areas with yield greater than 2 tons / ha	4 tons / ha	Land areas with yield greater than 2 tons / ha	4 tons / ha
	km²		% land area									%	%	1000 ha	1000 ha
Algeria	2 316 559	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Angola	1 247 357	59%	27%	13%	1%	0%	0%	0%	0%	0%	100%	1%	0%	1 463	-
Benin	115 543	47%	39%	13%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Botswana	578 084	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Burkina Faso	273 367	96%	4%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Burundi	26 949	51%	41%	7%	1%	0%	0%	0%	0%	0%	100%	1%	0%	29	-
Cameroon	466 295	21%	17%	22%	19%	19%	1%	0%	0%	0%	100%	39%	1%	18 352	598
Central African Republic	620 200	9%	28%	53%	8%	2%	0%	0%	0%	0%	100%	10%	0%	5 996	88
Chad	1 269 961	98%	2%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Republic of Congo	341 574	3%	19%	32%	37%	8%	0%	0%	0%	0%	100%	46%	0%	15 641	50
Democratic Republic of the Congo	2 327 986	6%	14%	26%	33%	21%	0%	0%	0%	0%	100%	55%	0%	127 830	1 152
Côte d'Ivoire	321 882	7%	33%	31%	27%	2%	0%	0%	0%	0%	100%	29%	0%	9 365	-
Djibouti	21 679	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Egypt	982 446	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Equatorial Guinea	26 987	7%	26%	41%	25%	1%	0%	0%	0%	0%	100%	27%	0%	720	-
Eritrea	122 098	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Ethiopia	1 127 582	85%	12%	3%	0%	0%	0%	0%	0%	0%	100%	0%	0%	359	-
Gabon	264 715	10%	31%	38%	20%	0%	0%	0%	0%	0%	100%	21%	0%	5 445	-
Gambia	10 797	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Ghana	238 761	25%	28%	24%	18%	5%	0%	0%	0%	0%	100%	23%	0%	5 566	78
Guinea	244 871	46%	30%	19%	5%	0%	0%	0%	0%	0%	100%	6%	0%	1 378	-
Guinea-Bissau	33 974	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-

Country	Area	Restricted land	Yield values (tons/ha)									Land areas with yield greater than		Land areas with yield greater than	
			0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8		2 tons / ha	4 tons / ha	2 tons / ha	4 tons / ha
	km²		% land area									%	%	1000 ha	1000 ha
Kenya	582 253	79%	10%	6%	2%	1%	1%	0%	0%	0%	100%	5%	1%	2 773	845
Lesotho	30 454	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Liberia	95 877	1%	22%	53%	24%	0%	0%	0%	0%	0%	100%	24%	0%	2 311	-
Libya	1 616 869	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Madagascar	591 575	30%	35%	15%	9%	6%	2%	2%	2%	0%	100%	21%	7%	12 444	3 963
Malawi	118 062	53%	38%	7%	2%	0%	0%	0%	0%	0%	100%	2%	0%	179	-
Mali	1 251 574	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Mauritania	1 040 738	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Morocco	406 318	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Mozambique	786 096	27%	33%	24%	10%	4%	1%	0%	0%	0%	100%	15%	1%	12 020	974
Namibia	824 205	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Niger	1 183 766	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Nigeria	909 481	59%	27%	12%	1%	0%	0%	0%	0%	0%	100%	2%	0%	1 398	-
Rwanda	25 206	73%	9%	11%	6%	0%	0%	0%	0%	0%	100%	6%	0%	158	-
Senegal	196 761	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Sierra Leone	72 322	34%	60%	6%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Somalia	633 217	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
South Africa	1 220 394	94%	4%	1%	0%	0%	0%	0%	0%	0%	100%	1%	0%	994	137
Sudan	2 503 827	90%	7%	3%	1%	0%	0%	0%	0%	0%	100%	1%	0%	2 937	-
Swaziland	17 289	81%	19%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Tanzania	941 758	33%	36%	22%	7%	2%	0%	0%	0%	0%	100%	9%	0%	8 587	196
Togo	57 038	23%	43%	25%	8%	1%	0%	0%	0%	0%	100%	9%	0%	526	19
Tunisia	155 176	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Uganda	241 278	20%	10%	16%	18%	22%	12%	2%	0%	0%	100%	53%	14%	12 899	3 381
Zambia	751 315	54%	44%	3%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Zimbabwe	390 649	93%	7%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-

Note: Percentage values represent land area shares.

Table 15: Total land areas without applying any restriction criteria and their potential (irrigated) sugarcane yield in tons of sugar/ha

Country	Area	Restricted land	Yield values (tons/ha) 0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8		Land areas with yield greater than 2 tons / ha	4 tons / ha	Land areas with yield greater than 2 tons / ha	4 tons / ha
	km²	% land area										%	%	1000 ha	1000 ha
Algeria	2 316 559	98%	1%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	546	8
Angola	1 247 357	48%	19%	12%	10%	7%	4%	0%	0%	0%	100%	22%	5%	27 345	6 022
Benin	115 543	0%	8%	70%	18%	4%	0%	0%	0%	0%	100%	23%	0%	2 608	-
Botswana	578 084	77%	11%	5%	4%	2%	1%	0%	0%	0%	100%	8%	1%	4 460	772
Burkina Faso	273 367	9%	38%	34%	15%	3%	0%	0%	0%	0%	100%	19%	0%	5 083	-
Burundi	26 949	49%	34%	13%	4%	0%	0%	0%	0%	0%	100%	5%	0%	126	10
Cameroon	466 295	8%	16%	26%	26%	19%	5%	0%	0%	0%	100%	50%	6%	23 423	2 599
Central African Republic	620 200	9%	16%	51%	19%	4%	1%	0%	0%	0%	100%	24%	1%	14 932	460
Chad	1 269 961	68%	13%	8%	7%	4%	0%	0%	0%	0%	100%	11%	0%	13 826	46
Republic of Congo	341 574	23%	24%	38%	14%	1%	0%	0%	0%	0%	100%	15%	0%	5 184	-
Democratic Republic of the Congo	2 327 986	7%	11%	25%	28%	25%	3%	0%	0%	0%	100%	56%	3%	131 056	7 873
Côte d'Ivoire	321 882	3%	35%	48%	14%	1%	0%	0%	0%	0%	100%	15%	0%	4 717	58
Djibouti	21 679	99%	1%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Egypt	982 446	92%	3%	4%	1%	0%	0%	0%	0%	0%	100%	1%	0%	1 019	8
Equatorial Guinea	26 987	26%	29%	29%	17%	0%	0%	0%	0%	0%	100%	17%	0%	450	-
Eritrea	122 098	74%	10%	8%	4%	2%	2%	1%	0%	0%	100%	8%	2%	1 012	294
Ethiopia	1 127 582	53%	16%	11%	8%	5%	3%	2%	1%	1%	100%	19%	6%	21 528	6 936
Gabon	264 715	32%	34%	25%	9%	0%	0%	0%	0%	0%	100%	9%	0%	2 355	-
Gambia	10 797	0%	16%	49%	24%	9%	3%	0%	0%	0%	100%	35%	3%	379	28
Ghana	238 761	6%	17%	62%	14%	1%	0%	0%	0%	0%	100%	16%	0%	3 701	20
Guinea	244 871	14%	27%	26%	25%	7%	2%	0%	0%	0%	100%	34%	2%	8 386	479
Guinea-Bissau	33 974	5%	25%	24%	28%	19%	1%	0%	0%	0%	100%	47%	1%	1 607	39
Kenya	582 253	26%	19%	12%	11%	9%	9%	7%	4%	2%	100%	42%	22%	24 388	13 040

Country	Area	Restricted land	Yield values (tons/ha)									Land areas with yield greater than		Land areas with yield greater than	
			0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8		2 tons / ha	4 tons / ha	2 tons / ha	4 tons / ha
	km²	% land area										%	%	1000 ha	1000 ha
Lesotho	30 454	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Liberia	95 877	2%	48%	49%	1%	0%	0%	0%	0%	0%	100%	1%	0%	118	-
Libya	1 616 869	95%	3%	2%	1%	0%	0%	0%	0%	0%	100%	1%	0%	1 401	-
Madagascar	591 575	26%	28%	21%	10%	7%	5%	3%	0%	0%	100%	26%	9%	15 295	5 084
Malawi	118 062	24%	14%	14%	19%	16%	10%	4%	0%	0%	100%	49%	13%	5 781	1 575
Mali	1 251 574	78%	6%	9%	4%	2%	1%	0%	0%	0%	100%	7%	1%	8,522	1 560
Mauritania	1 040 738	99%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	201	-
Morocco	406 318	78%	9%	7%	4%	2%	1%	0%	0%	0%	100%	6%	1%	2 620	310
Mozambique	786 096	9%	12%	15%	17%	22%	14%	6%	3%	1%	100%	63%	24%	49 778	19 106
Namibia	824 205	94%	3%	2%	1%	0%	0%	0%	0%	0%	100%	1%	0%	779	60
Niger	1 183 766	91%	7%	1%	1%	0%	0%	0%	0%	0%	100%	1%	0%	1 346	-
Nigeria	909 481	15%	21%	36%	17%	8%	2%	0%	0%	0%	100%	28%	3%	25 218	2 556
Rwanda	25 206	75%	9%	9%	7%	1%	0%	0%	0%	0%	100%	7%	0%	187	-
Senegal	196 761	29%	44%	16%	6%	4%	0%	0%	0%	0%	100%	11%	0%	2, 40	-
Sierra Leone	72 322	18%	45%	35%	1%	0%	0%	0%	0%	0%	100%	1%	0%	107	-
Somalia	633 217	78%	13%	3%	2%	3%	0%	0%	0%	0%	100%	5%	0%	3 015	196
South Africa	1 220 394	62%	10%	9%	7%	5%	3%	2%	1%	0%	100%	19%	7%	23 194	8 505
Sudan	2 503 827	56%	19%	10%	7%	4%	2%	1%	0%	0%	100%	15%	3%	37 730	8 398
Swaziland	17 289	23%	38%	35%	3%	0%	0%	0%	0%	0%	100%	4%	0%	65	-
Tanzania	941 758	15%	14%	19%	20%	16%	10%	4%	1%	0%	100%	52%	15%	48 684	14 188
Togo	57 038	6%	24%	54%	15%	2%	0%	0%	0%	0%	100%	17%	0%	947	19
Tunisia	155 176	77%	17%	5%	1%	0%	0%	0%	0%	0%	100%	1%	0%	198	14
Uganda	241 278	20%	9%	12%	19%	20%	15%	4%	0%	0%	100%	59%	20%	14 143	4 873
Zambia	751 315	3%	18%	16%	15%	21%	24%	2%	1%	0%	100%	63%	28%	47 501	20 744
Zimbabwe	390 649	26%	17%	17%	15%	11%	7%	4%	2%	1%	100%	40%	14%	15 722	5 493

Note: Irrigated sugarcane, assuming no water deficit; percentage values represent land area shares based on total country area.

Table 16: Available land areas after applying restriction criteria and their potential (rain-fed) sugarcane yield in tons of sugar/ha

Country	Area	Restricted land	Yield values (tons/ha)									Land areas with yield greater than		Land areas with yield greater than	
			0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8		2 tons / ha	4 tons / ha	2 tons / ha	4 tons / ha
	km²		% land area									%	%	1000 ha	1000 ha
Algeria	2 316 559	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Angola	1 247 357	81%	12%	6%	0%	0%	0%	0%	0%	0%	100%	0%	0%	547	-
Benin	115 543	68%	24%	8%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Botswana	578 084	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Burkina Faso	273 367	98%	2%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Burundi	26 949	67%	28%	5%	0%	0%	0%	0%	0%	0%	100%	0%	0%	10	-
Cameroon	466 295	73%	9%	9%	5%	3%	0%	0%	0%	0%	100%	8%	0%	3 922	108
Central African Republic	620 200	46%	18%	33%	4%	1%	0%	0%	0%	0%	100%	4%	0%	2 666	49
Chad	1 269 961	99%	1%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Republic of Congo	341 574	82%	5%	6%	6%	1%	0%	0%	0%	0%	100%	7%	0%	2 399	-
Democratic Republic of the Congo	2 327 986	80%	5%	7%	5%	3%	0%	0%	0%	0%	100%	8%	0%	18 047	158
Côte d'Ivoire	321 882	54%	22%	15%	8%	0%	0%	0%	0%	0%	100%	8%	0%	2 700	-
Djibouti	21 679	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Egypt	982 446	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Equatorial Guinea	26 987	89%	2%	4%	5%	0%	0%	0%	0%	0%	100%	5%	0%	138	-
Eritrea	122 098	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Ethiopia	1 127 582	93%	6%	2%	0%	0%	0%	0%	0%	0%	100%	0%	0%	194	-
Gabon	264 715	91%	3%	5%	2%	0%	0%	0%	0%	0%	100%	2%	0%	477	-
Gambia	10 797	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Ghana	238 761	66%	14%	11%	6%	2%	0%	0%	0%	0%	100%	8%	0%	1 992	39
Guinea	244 871	62%	20%	14%	4%	0%	0%	0%	0%	0%	100%	4%	0%	1 048	-
Guinea-Bissau	33 974	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Kenya	582 253	90%	5%	3%	1%	1%	0%	0%	0%	0%	100%	2%	1%	1 230	317
Lesotho	30 454	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-

Country	Area	Restricted land	Yield values (tons/ha) 0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8		Land areas with yield greater than 2 tons / ha	Land areas with yield greater than 4 tons / ha	Land areas with yield greater than 2 tons / ha	Land areas with yield greater than 4 tons / ha
	km²	% land area										%	%	1000 ha	1000 ha
Liberia	95 877	83%	3%	9%	5%	0%	0%	0%	0%	0%	100%	5%	0%	489	-
Libya	1 616 869	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Madagascar	591 575	76%	12%	5%	3%	2%	1%	1%	1%	0%	100%	8%	3%	4 561	1 544
Malawi	118 062	93%	6%	1%	0%	0%	0%	0%	0%	0%	100%	0%	0%	47	-
Mali	1 251 574	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Mauritania	1 040 738	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Morocco	406 318	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Mozambique	786 096	72%	12%	10%	3%	2%	1%	0%	0%	0%	100%	6%	1%	5 058	811
Namibia	824 205	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Niger	1 183 766	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Nigeria	909 481	82%	12%	5%	0%	0%	0%	0%	0%	0%	100%	0%	0%	434	-
Rwanda	25 206	87%	7%	5%	2%	0%	0%	0%	0%	0%	100%	2%	0%	39	-
Senegal	196 761	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Sierra Leone	72 322	78%	20%	2%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Somalia	633 217	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
South Africa	1 220 394	96%	3%	1%	0%	0%	0%	0%	0%	0%	100%	0%	0%	440	84
Sudan	2 503 827	93%	4%	2%	1%	0%	0%	0%	0%	0%	100%	1%	0%	2 516	-
Swaziland	17 289	91%	9%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Tanzania	941 758	78%	11%	8%	3%	1%	0%	0%	0%	0%	100%	4%	0%	3 716	78
Togo	57 038	45%	29%	19%	6%	1%	0%	0%	0%	0%	100%	7%	0%	398	19
Tunisia	155 176	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Uganda	241 278	69%	5%	7%	6%	9%	3%	1%	0%	0%	100%	20%	4%	4 774	1 000
Zambia	751 315	81%	18%	2%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Zimbabwe	390 649	98%	2%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-

Note: Restriction criteria include protected areas, wetlands, forests and agricultural areas; percentage values represent land area shares based on total country area.

Table 17: Available land areas after applying restriction criteria and their potential (irrigated) sugarcane yield in tons of sugar/ha

Country	Area	Restricted land	Yield values (tons/ha)									Land areas with yield greater than		Land areas with yield greater than	
			0 -1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8		2 tons / ha	4 tons / ha	2 tons / ha	4 tons / ha
	km²		% land area									%	%	1000 ha	1000 ha
Algeria	2 316 559	99%	1%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	115	-
Angola	1 247 357	75%	8%	6%	5%	4%	2%	0%	0%	0%	100%	12%	3%	14 713	3 223
Benin	115 543	56%	2%	32%	9%	1%	0%	0%	0%	0%	100%	10%	0%	1 104	-
Botswana	578 084	91%	4%	2%	1%	1%	0%	0%	0%	0%	100%	3%	1%	1 549	330
Burkina Faso	273 367	49%	24%	18%	7%	2%	0%	0%	0%	0%	100%	9%	0%	2 489	-
Burundi	26 949	64%	25%	9%	3%	0%	0%	0%	0%	0%	100%	3%	0%	71	-
Cameroon	466 295	66%	5%	10%	10%	6%	2%	0%	0%	0%	100%	19%	3%	8 873	1 206
Central African Republic	620 200	45%	11%	32%	9%	2%	0%	0%	0%	0%	100%	12%	0%	7 243	294
Chad	1 269 961	85%	7%	3%	3%	2%	0%	0%	0%	0%	100%	4%	0%	5 554	18
Republic of Congo	341 574	90%	6%	4%	1%	0%	0%	0%	0%	0%	100%	1%	0%	297	-
Democratic Republic of the Congo	2 327 986	80%	2%	3%	5%	7%	1%	0%	0%	0%	100%	14%	1%	31 882	3 441
Côte d'Ivoire	321 882	51%	17%	22%	9%	1%	0%	0%	0%	0%	100%	10%	0%	3 207	49
Djibouti	21 679	99%	1%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Egypt	982 446	97%	2%	1%	0%	0%	0%	0%	0%	0%	100%	0%	0%	453	-
Equatorial Guinea	26 987	90%	3%	4%	4%	0%	0%	0%	0%	0%	100%	4%	0%	99	-
Eritrea	122 098	80%	7%	6%	3%	1%	1%	1%	0%	0%	100%	6%	2%	789	241
Ethiopia	1 127 582	79%	7%	5%	4%	2%	1%	1%	0%	0%	100%	9%	2%	10 086	2 628
Gabon	264 715	94%	3%	2%	1%	0%	0%	0%	0%	0%	100%	1%	0%	179	-
Gambia	10 797	43%	9%	28%	12%	7%	1%	0%	0%	0%	100%	20%	1%	214	9
Ghana	238 761	59%	6%	27%	8%	1%	0%	0%	0%	0%	100%	9%	0%	2 041	20
Guinea	244 871	42%	16%	18%	19%	4%	1%	0%	0%	0%	100%	24%	1%	5 999	240
Guinea-Bissau	33 974	53%	7%	10%	15%	14%	1%	0%	0%	0%	100%	30%	1%	1 019	39

Country	Area	Restricted land	Yield values (tons/ha)									Land areas with yield greater than		Land areas with yield greater than	
			0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8		2 tons / ha	4 tons / ha	2 tons / ha	4 tons / ha
	km²	% land area										%	%	1000 ha	1000 ha
Kenya	582 253	59%	12%	7%	6%	5%	4%	3%	2%	1%	100%	22%	11%	12 763	6 292
Lesotho	30 454	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Liberia	95 877	83%	8%	9%	0%	0%	0%	0%	0%	0%	100%	0%	0%	29	-
Libya	1 616 869	96%	2%	1%	0%	0%	0%	0%	0%	0%	100%	1%	0%	1 204	-
Madagascar	591 575	75%	9%	7%	4%	3%	2%	1%	0%	0%	100%	9%	3%	5 479	1 765
Malawi	118 062	86%	3%	3%	3%	3%	1%	1%	0%	0%	100%	7%	2%	840	198
Mali	1 251 574	86%	4%	6%	3%	1%	1%	0%	0%	0%	100%	4%	1%	5 283	694
Mauritania	1 040 738	99%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	167	-
Morocco	406 318	91%	5%	2%	1%	0%	0%	0%	0%	0%	100%	2%	0%	669	50
Mozambique	786 096	65%	5%	6%	7%	8%	6%	2%	1%	1%	100%	24%	9%	18 671	7 300
Namibia	824 205	97%	1%	1%	0%	0%	0%	0%	0%	0%	100%	1%	0%	445	43
Niger	1 183 766	92%	6%	1%	1%	0%	0%	0%	0%	0%	100%	1%	0%	1 237	-
Nigeria	909 481	61%	10%	16%	8%	4%	1%	0%	0%	0%	100%	13%	1%	12 000	974
Rwanda	25 206	88%	6%	3%	3%	0%	0%	0%	0%	0%	100%	3%	0%	69	-
Senegal	196 761	61%	24%	10%	3%	2%	0%	0%	0%	0%	100%	4%	0%	884	-
Sierra Leone	72 322	72%	14%	14%	1%	0%	0%	0%	0%	0%	100%	1%	0%	38	-
Somalia	633 217	91%	6%	1%	1%	1%	0%	0%	0%	0%	100%	2%	0%	1 000	127
South Africa	1 220 394	77%	7%	5%	4%	3%	2%	1%	1%	0%	100%	10%	4%	12 589	4 556
Sudan	2 503 827	73%	10%	6%	5%	3%	2%	0%	0%	0%	100%	11%	2%	26 716	6 094
Swaziland	17 289	55%	24%	18%	3%	1%	0%	0%	0%	0%	100%	4%	0%	65	-
Tanzania	941 758	74%	4%	6%	6%	5%	3%	1%	0%	0%	100%	16%	5%	15 354	4 714
Togo	57 038	40%	13%	34%	11%	1%	0%	0%	0%	0%	100%	13%	0%	728	19
Tunisia	155 176	86%	10%	3%	1%	0%	0%	0%	0%	0%	100%	1%	0%	150	14
Uganda	241 278	68%	4%	4%	6%	8%	7%	2%	0%	0%	100%	23%	9%	5 616	2 258
Zambia	751 315	72%	4%	3%	4%	8%	9%	0%	0%	0%	100%	21%	9%	15 769	7 013
Zimbabwe	390 649	80%	3%	4%	4%	3%	2%	2%	2%	0%	100%	13%	6%	5 189	2 479

Note: Restriction criteria include protected areas, wetlands, forests and agricultural areas. Irrigated sugarcane, assuming no water deficit for the crop; percentage values represent land area shares based on total country area.

Table 18: Calculation of ethanol production from sugarcane on different land areas using rain-fed and irrigated sugarcane.

Country	Energy potentials					
	Total land area		Total land area - Restricted			
	rain-fed		rain- fed		irrigated	
	> 2 ton/ ha	> 4 ton/ ha	> 2 ton/ ha	> 4 ton/ ha	> 2 ton/ ha	> 4 ton/ ha
	million litres of ethanol					
Algeria	-	-	-	-	200	-
Angola	2 200	-	800	-	29 100	12 000
Benin	-	-	-	-	1 600	-
Botswana	-	-	-	-	3 000	1 200
Burkina Faso	-	-	-	-	3 700	-
Burundi	-	-	-	-	100	-
Cameroon	28 700	2 200	6 100	400	15 900	4 500
Central African Republic	9 100	300	4 100	200	11 400	1 100
Chad	-	-	-	-	8 300	100
Republic of Congo	23 400	200	3 600	-	400	-
Democratic Republic of the Congo	193 000	4 300	27 200	600	55 200	12 800
Côte d'Ivoire	14 000	-	4 000	-	4 900	200
Djibouti	-	-	-	-	-	-
Egypt	-	-	-	-	700	-
Equatorial Guinea	1 100	-	200	-	100	-
Eritrea	-	-	-	-	1 700	900
Ethiopia	500	-	300	-	20 900	9 800
Gabon	8 100	-	700	-	300	-
Gambia	-	-	-	-	300	-
Ghana	8 500	300	3 100	100	3 100	100
Guinea	2 100	-	1 600	-	9 500	900
Guinea-Bissau	-	-	-	-	1 600	100

Country	Energy potentials					
	Total land area		Total land area - Restricted			
	rain-fed		rain- fed		irrigated	
	> 2 ton/ ha	> 4 ton/ ha	> 2 ton/ ha	> 4 ton/ ha	> 2 ton/ ha	> 4 ton/ ha
	million litres of ethanol					
Kenya	6 000	3 100	2 500	1 200	33 100	23 400
Lesotho	-	-	-	-	-	-
Liberia	3 400	-	700	-	-	-
Libya	-	-	-	-	1 800	-
Madagascar	27 400	14 800	10 200	5 800	12 100	6 600
Malawi	300	-	100	-	1 700	700
Mali	-	-	-	-	9 400	2 600
Mauritania	-	-	-	-	200	-
Morocco	-	-	-	-	1 100	200
Mozambique	20 100	3 600	9 300	3 000	44 100	27 200
Namibia	-	-	-	-	800	200
Niger	-	-	-	-	1 800	-
Nigeria	2 100	-	600	-	20 100	3 600
Rwanda	200	-	100	-	100	-
Senegal	-	-	-	-	1 300	-
Sierra Leone	-	-	-	-	100	-
Somalia	-	-	-	-	1 800	500
South Africa	1 800	500	800	300	28 900	17 000

Country	Energy potentials					
	Total land area		Total land area - Restricted			
	rain-fed		rain- fed		irrigated	
	> 2 ton/ ha	> 4 ton/ ha	> 2 ton/ ha	> 4 ton/ ha	> 2 ton/ ha	> 4 ton/ ha
	million litres of ethanol					
Sudan	4 400	-	3 700	-	53 400	22 700
Swaziland	-	-	-	-	100	-
Tanzania	13 200	700	5 700	300	33 400	17 600
Togo	800	100	600	100	1 100	100
Tunisia	-	-	-	-	300	100
Uganda	26 800	12 600	9 300	3 700	13 400	8 400
Zambia	-	-	-	-	39 200	26 100
Zimbabwe	-	-	-	-	13 300	9 200

Note: The first two columns represent no restrictions to the total country area, while columns 3 to 6 represent actually available land areas (restrictions apply as explained in the text). Ethanol production is calculated for best producing areas (e.g. areas with yields higher than 2 and 4 tons of sugar per hectare)

Table 19: Total land areas without applying any restriction criteria and their potential (rain-fed) Jatropha yield in tons/ha (dry mass)

Country	Area	Yield values (tons/ha)							Land areas with yield greater than		Land areas with yield greater than	
		Restricted land	0.5 - 1	1 - 1.5	1.5 - 2	2 - 2.5	2.5 - 3		1 tons / ha	2 tons / ha	1 tons / ha	2 tons / ha
	km²	% land area							%	%	1000 ha	1000 ha
Algeria	2 316 559	99%	1%	0%	0%	0%	0%	100%	0%	0%	208	-
Angola	1 247 357	51%	27%	22%	0%	0%	0%	100%	22%	0%	27 854	-
Benin	115 543	36%	53%	11%	0%	0%	0%	100%	11%	0%	1 266	-
Botswana	578 084	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Burkina Faso	273 367	91%	8%	1%	0%	0%	0%	100%	1%	0%	331	-
Burundi	26 949	57%	41%	2%	0%	0%	0%	100%	2%	0%	58	-
Cameroon	466 295	28%	36%	35%	1%	0%	0%	100%	36%	0%	16 841	-
Central African Republic	620 200	9%	62%	29%	0%	0%	0%	100%	29%	0%	17 901	-
Chad	1 269 961	96%	4%	0%	0%	0%	0%	100%	0%	0%	-	-
Republic of Congo	341 574	35%	57%	8%	0%	0%	0%	100%	8%	0%	2 676	-
Democratic Republic of the Congo	2 327 986	9%	41%	50%	0%	0%	0%	100%	51%	0%	118 010	286
Côte d'Ivoire	321 882	10%	71%	19%	0%	0%	0%	100%	19%	0%	6 208	-
Djibouti	21 679	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Egypt	982 446	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Equatorial Guinea	26 987	86%	13%	0%	0%	0%	0%	100%	0%	0%	10	-
Eritrea	122 098	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Ethiopia	1 127 582	82%	13%	4%	1%	0%	0%	100%	5%	0%	5 826	19
Gabon	264 715	51%	49%	0%	0%	0%	0%	100%	0%	0%	-	-
Gambia	10 797	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Ghana	238 761	27%	44%	26%	4%	0%	0%	100%	29%	0%	7 041	-
Guinea	244 871	45%	33%	22%	0%	0%	0%	100%	22%	0%	5 370	-
Guinea-Bissau	33 974	54%	46%	0%	0%	0%	0%	100%	0%	0%	-	-
Kenya	582 253	73%	13%	10%	4%	0%	0%	100%	14%	0%	8 160	40

Country	Area	Restricted land	Yield values (tons/ha)						Land areas with yield greater than		Land areas with yield greater than	
			0.5 - 1	1 - 1.5	1.5 - 2	2 - 2.5	2.5 - 3		1 tons / ha	2 tons / ha	1 tons / ha	2 tons / ha
	km^2		% land area						%	%	1000 ha	1000 ha
Lesotho	30 454	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Liberia	95 877	64%	36%	0%	0%	0%	0%	100%	0%	0%	-	-
Libya	1 616 869	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Madagascar	591 575	44%	29%	15%	9%	3%	0%	100%	27%	3%	15 842	1 986
Malawi	118 062	39%	48%	13%	0%	0%	0%	100%	13%	0%	1 480	-
Mali	1 251 574	98%	2%	0%	0%	0%	0%	100%	0%	0%	-	-
Mauritania	1 040 738	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Morocco	406 318	92%	8%	0%	0%	0%	0%	100%	0%	0%	144	-
Mozambique	786 096	19%	26%	42%	11%	1%	0%	100%	55%	1%	42 866	938
Namibia	824 205	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Niger	1 183 766	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Nigeria	909 481	56%	33%	10%	1%	0%	0%	100%	11%	0%	9 836	-
Rwanda	25 206	70%	16%	14%	0%	0%	0%	100%	14%	0%	345	-
Senegal	196 761	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Sierra Leone	72 322	51%	49%	0%	0%	0%	0%	100%	0%	0%	10	-
Somalia	633 217	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
South Africa	1 220 394	91%	6%	3%	0%	0%	0%	100%	3%	0%	3 642	-
Sudan	2 503 827	88%	7%	5%	1%	0%	0%	100%	5%	0%	13 578	-
Swaziland	17 289	51%	45%	3%	0%	0%	0%	100%	3%	0%	57	-
Tanzania	941 758	29%	38%	31%	2%	0%	0%	100%	33%	0%	31 402	20
Togo	57 038	14%	64%	21%	1%	0%	0%	100%	22%	0%	1 244	-
Tunisia	155 176	99%	1%	0%	0%	0%	0%	100%	0%	0%	-	-
Uganda	241 278	26%	40%	32%	2%	0%	0%	100%	34%	0%	8 295	50
Zambia	751 315	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Zimbabwe	390 649	39%	49%	12%	0%	0%	0%	100%	12%	0%	4 549	-

Note: Percentage values represent land area shares based on total country area.

Table 20: Available land areas after applying restriction criteria and their potential (rain-fed) Jatropha yield in tons/ha (dry mass)

Country	Area	Restricted land	Yield values (tons/ha) 0.5 - 1	1 - 1.5	1.5 - 2	2 - 2.5	2.5 - 3		Land areas with yield greater than 1 tons / ha	Land areas with yield greater than 2 tons / ha	Land areas with yield greater than 1 tons / ha	Land areas with yield greater than 2 tons / ha
	km²	% land area							%	%	1000 ha	1000 ha
Algeria	2 316 559	100%	0%	0%	0%	0%	0%	100%	0%	0%	115	-
Angola	1 247 357	76%	14%	10%	0%	0%	0%	100%	10%	0%	12 272	-
Benin	115 543	64%	31%	5%	0%	0%	0%	100%	5%	0%	630	-
Botswana	578 084	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Burkina Faso	273 367	96%	4%	1%	0%	0%	0%	100%	1%	0%	142	-
Burundi	26 949	72%	28%	0%	0%	0%	0%	100%	0%	0%	10	-
Cameroon	466 295	73%	14%	12%	0%	0%	0%	100%	12%	0%	5 785	-
Central African Republic	620 200	46%	38%	17%	0%	0%	0%	100%	17%	0%	10 467	-
Chad	1 269 961	98%	2%	0%	0%	0%	0%	100%	0%	0%	-	-
Republic of Congo	341 574	85%	13%	2%	0%	0%	0%	100%	2%	0%	793	-
Democratic Republic of the Congo	2 327 986	80%	8%	12%	0%	0%	0%	100%	12%	0%	28 170	59
Côte d'Ivoire	321 882	55%	34%	12%	0%	0%	0%	100%	12%	0%	3 724	-
Djibouti	21 679	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Egypt	982 446	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Equatorial Guinea	26 987	98%	2%	0%	0%	0%	0%	100%	0%	0%	-	-
Eritrea	122 098	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Ethiopia	1 127 582	92%	6%	2%	0%	0%	0%	100%	2%	0%	2 228	-
Gabon	264 715	94%	6%	0%	0%	0%	0%	100%	0%	0%	-	-
Gambia	10 797	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Ghana	238 761	69%	19%	10%	2%	0%	0%	100%	13%	0%	3 008	-
Guinea	244 871	61%	22%	17%	0%	0%	0%	100%	17%	0%	4 144	-
Guinea-Bissau	33 974	74%	26%	0%	0%	0%	0%	100%	0%	0%	-	-
Kenya	582 253	86%	6%	5%	3%	0%	0%	100%	7%	0%	4 306	30

Country	Area	Restricted land	Yield values (tons/ha) 0.5 - 1	1 - 1.5	1.5 - 2	2 - 2.5	2.5 - 3		Land areas with yield greater than 1 tons / ha	2 tons / ha	Land areas with yield greater than 1 tons / ha	2 tons / ha
	km²		% land area						%	%	1000 ha	1000 ha
Lesotho	30 454	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Liberia	95 877	92%	8%	0%	0%	0%	0%	100%	0%	0%	-	-
Libya	1 616 869	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Madagascar	591 575	80%	10%	5%	3%	1%	0%	100%	10%	1%	5 894	723
Malawi	118 062	90%	8%	2%	0%	0%	0%	100%	2%	0%	226	-
Mali	1 251 574	99%	1%	0%	0%	0%	0%	100%	0%	0%	-	-
Mauritania	1 040 738	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Morocco	406 318	97%	3%	0%	0%	0%	0%	100%	0%	0%	7	-
Mozambique	786 096	68%	10%	16%	5%	1%	0%	100%	22%	1%	16 932	649
Namibia	824 205	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Niger	1 183 766	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Nigeria	909 481	81%	15%	4%	1%	0%	0%	100%	5%	0%	4 177	-
Rwanda	25 206	84%	9%	7%	0%	0%	0%	100%	7%	0%	177	-
Senegal	196 761	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Sierra Leone	72 322	84%	16%	0%	0%	0%	0%	100%	0%	0%	10	-
Somalia	633 217	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
South Africa	1 220 394	95%	4%	1%	0%	0%	0%	100%	2%	0%	1 921	-
Sudan	2 503 827	91%	5%	3%	1%	0%	0%	100%	4%	0%	9 943	-
Swaziland	17 289	72%	25%	2%	0%	0%	0%	100%	2%	0%	40	-
Tanzania	941 758	77%	13%	10%	1%	0%	0%	100%	11%	0%	10 268	-
Togo	57 038	43%	40%	17%	1%	0%	0%	100%	17%	0%	980	-
Tunisia	155 176	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Uganda	241 278	72%	17%	11%	1%	0%	0%	100%	11%	0%	2 734	30
Zambia	751 315	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Zimbabwe	390 649	78%	16%	6%	0%	0%	0%	100%	6%	0%	2 499	-

Note: Restriction criteria include protected areas, wetlands, forests and agricultural areas; percentage values represent land area shares based on total country area.

Table 21: Total land areas without applying any restriction criteria and their potential (rain-fed) soybean yield in tons/ha (dry mass)

Country	Area	Restricted land	Yield values (tons/ha) 0.5 - 1	1 - 1.5	1.5 - 2	2 - 2.5	2.5 - 3		Land areas with yield greater than 1 tons / ha	Land areas with yield greater than 2 tons / ha	Land areas with yield greater than 1 tons / ha	Land areas with yield greater than 2 tons / ha
	km²	% land area							%	%	1000 ha	1000 ha
Algeria	2 316 559	98%	1%	0%	0%	0%	0%	100%	0%	0%	223	-
Angola	1 247 357	10%	24%	52%	14%	0%	0%	100%	66%	0%	82 185	463
Benin	115 543	1%	16%	73%	8%	3%	0%	100%	84%	3%	9 661	328
Botswana	578 084	61%	27%	10%	1%	0%	0%	100%	12%	0%	6 698	-
Burkina Faso	273 367	15%	44%	32%	9%	0%	0%	100%	41%	0%	11 094	76
Burundi	26 949	54%	41%	4%	0%	0%	0%	100%	5%	0%	126	-
Cameroon	466 295	23%	45%	27%	5%	0%	0%	100%	32%	0%	15 125	186
Central African Republic	620 200	1%	48%	46%	5%	0%	0%	100%	51%	0%	31 500	39
Chad	1 269 961	74%	11%	7%	8%	0%	0%	100%	15%	0%	19 014	74
Republic of Congo	341 574	43%	56%	1%	0%	0%	0%	100%	1%	0%	337	-
Democratic Republic of the Congo	2 327 986	9%	49%	31%	11%	0%	0%	100%	42%	0%	96 882	364
Côte d'Ivoire	321 882	5%	52%	41%	2%	0%	0%	100%	43%	0%	13 965	58
Djibouti	21 679	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Egypt	982 446	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Equatorial Guinea	26 987	83%	17%	0%	0%	0%	0%	100%	0%	0%	-	-
Eritrea	122 098	95%	5%	0%	0%	0%	0%	100%	0%	0%	55	-
Ethiopia	1 127 582	66%	17%	10%	5%	2%	0%	100%	17%	2%	18 806	1 939
Gabon	264 715	77%	23%	0%	0%	0%	0%	100%	0%	0%	-	-
Gambia	10 797	1%	65%	34%	0%	0%	0%	100%	34%	0%	369	-
Ghana	238 761	9%	28%	54%	8%	1%	0%	100%	63%	1%	15 097	156
Guinea	244 871	29%	36%	21%	13%	1%	0%	100%	35%	1%	8 472	172
Guinea-Bissau	33 974	6%	34%	34%	26%	0%	0%	100%	61%	0%	2 062	-
Kenya	582 253	51%	19%	15%	9%	4%	1%	100%	30%	5%	17 255	2 912
Lesotho	30 454	60%	24%	14%	3%	0%	0%	100%	16%	0%	495	-
Liberia	95 877	80%	20%	0%	0%	0%	0%	100%	0%	0%	-	-

Country	Area	Restricted land	Yield values (tons/ha)						Land areas with yield greater than		Land areas with yield greater than	
			0.5 - 1	1 - 1.5	1.5 - 2	2 - 2.5	2.5 - 3		1 tons / ha	2 tons / ha	1 tons / ha	2 tons / ha
	km^2	% land area							%	%	1000 ha	1000 ha
Libya	1 616 869	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Madagascar	591 575	33%	19%	21%	14%	8%	5%	100%	48%	13%	28 506	7 572
Malawi	118 062	27%	17%	29%	20%	3%	3%	100%	55%	6%	6 544	698
Mali	1 251 574	80%	11%	6%	1%	1%	0%	100%	9%	1%	11 092	1 614
Mauritania	1 040 738	100%	0%	0%	0%	0%	0%	100%	0%	0%	9	-
Morocco	406 318	87%	13%	0%	0%	0%	0%	100%	0%	0%	151	-
Mozambique	786 096	6%	14%	32%	35%	11%	1%	100%	80%	12%	62 623	9 531
Namibia	824 205	81%	14%	5%	0%	0%	0%	100%	5%	0%	4 081	-
Niger	1 183 766	94%	4%	1%	0%	0%	0%	100%	2%	0%	1 779	-
Nigeria	909 481	16%	32%	39%	11%	2%	0%	100%	52%	2%	47 543	2 064
Rwanda	25 206	77%	7%	13%	3%	0%	0%	100%	16%	0%	404	-
Senegal	196 761	45%	43%	12%	0%	0%	0%	100%	12%	0%	2 382	-
Sierra Leone	72 322	46%	50%	4%	0%	0%	0%	100%	4%	0%	272	-
Somalia	633 217	99%	1%	0%	0%	0%	0%	100%	0%	0%	20	-
South Africa	1 220 394	59%	13%	18%	8%	2%	0%	100%	28%	2%	34 582	2 155
Sudan	2 503 827	69%	18%	8%	5%	0%	0%	100%	14%	0%	33 874	704
Swaziland	17 289	18%	59%	20%	3%	0%	0%	100%	23%	0%	404	-
Tanzania	941 758	17%	18%	34%	27%	4%	0%	100%	65%	4%	61 374	3 613
Togo	57 038	5%	33%	59%	2%	1%	0%	100%	62%	1%	3 541	38
Tunisia	155 176	98%	2%	0%	0%	0%	0%	100%	0%	0%	-	-
Uganda	241 278	25%	21%	36%	16%	2%	0%	100%	54%	2%	13 088	457
Zambia	751 315	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Zimbabwe	390 649	2%	12%	47%	34%	3%	2%	100%	86%	5%	33 664	1 834

Note: Percentage values represent land area shares based on total country area.

Table 22: Available land areas after applying restriction criteria and their potential (rain-fed) soybean yield in tons/ha (dry mass)

Country	Area	Yield values (tons/ha)							Land areas with yield greater than		Land areas with yield greater than	
		Restricted land	0.5 - 1	1 - 1.5	1.5 - 2	2 - 2.5	2.5 - 3		1 tons / ha	2 tons / ha	1 tons / ha	2 tons / ha
	km²	% land area							%	%	1000 ha	1000 ha
Algeria	2 316 559	99%	1%	0%	0%	0%	0%	100%	0%	0%	92	-
Angola	1 247 357	63%	9%	21%	8%	0%	0%	100%	28%	0%	35 468	339
Benin	115 543	56%	5%	36%	1%	1%	0%	100%	39%	1%	4 465	97
Botswana	578 084	80%	17%	3%	0%	0%	0%	100%	3%	0%	1 617	-
Burkina Faso	273 367	50%	31%	14%	5%	0%	0%	100%	18%	0%	5 006	28
Burundi	26 949	69%	28%	3%	0%	0%	0%	100%	3%	0%	71	-
Cameroon	466 295	68%	15%	14%	3%	0%	0%	100%	17%	0%	7 961	118
Central African Republic	620 200	42%	30%	26%	3%	0%	0%	100%	28%	0%	17 583	29
Chad	1 269 961	90%	5%	2%	3%	0%	0%	100%	6%	0%	7 191	37
Republic of Congo	341 574	88%	12%	0%	0%	0%	0%	100%	0%	0%	129	-
Democratic Republic of the Congo	2 327 986	80%	6%	9%	5%	0%	0%	100%	14%	0%	32 447	246
Côte d'Ivoire	321 882	51%	22%	26%	1%	0%	0%	100%	27%	0%	8 793	49
Djibouti	21 679	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Egypt	982 446	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Equatorial Guinea	26 987	97%	3%	0%	0%	0%	0%	100%	0%	0%	-	-
Eritrea	122 098	97%	3%	0%	0%	0%	0%	100%	0%	0%	46	-
Ethiopia	1 127 582	84%	9%	5%	2%	1%	0%	100%	7%	1%	8 128	659
Gabon	264 715	96%	4%	0%	0%	0%	0%	100%	0%	0%	-	-
Gambia	10 797	43%	35%	22%	0%	0%	0%	100%	22%	0%	233	-
Ghana	238 761	60%	11%	22%	6%	0%	0%	100%	28%	0%	6 797	49
Guinea	244 871	51%	24%	16%	9%	0%	0%	100%	25%	0%	6 172	77
Guinea-Bissau	33 974	53%	12%	17%	17%	0%	0%	100%	34%	0%	1 165	-
Kenya	582 253	75%	12%	7%	4%	2%	0%	100%	14%	3%	8 087	1 536
Lesotho	30 454	75%	18%	7%	0%	0%	0%	100%	7%	0%	222	-

Country	Area	Yield values (tons/ha)							Land areas with yield greater than		Land areas with yield greater than	
		Restricted land	0.5 - 1	1 - 1.5	1.5 - 2	2 - 2.5	2.5 - 3		1 tons / ha	2 tons / ha	1 tons / ha	2 tons / ha
	km^2	% land area							%	%	1000 ha	1000 ha
Liberia	95 877	95%	5%	0%	0%	0%	0%	100%	0%	0%	-	-
Libya	1 616 869	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Madagascar	591 575	76%	7%	8%	5%	3%	2%	100%	17%	5%	10 329	2 778
Malawi	118 062	86%	4%	5%	3%	0%	0%	100%	9%	1%	1 076	104
Mali	1 251 574	87%	8%	4%	1%	1%	0%	100%	5%	1%	6 194	757
Mauritania	1 040 738	100%	0%	0%	0%	0%	0%	100%	0%	0%	9	-
Morocco	406 318	96%	4%	0%	0%	0%	0%	100%	0%	0%	43	-
Mozambique	786 096	64%	5%	13%	13%	4%	1%	100%	31%	5%	24 172	3 850
Namibia	824 205	95%	4%	1%	0%	0%	0%	100%	1%	0%	915	-
Niger	1 183 766	95%	4%	1%	0%	0%	0%	100%	1%	0%	1 327	-
Nigeria	909 481	58%	18%	18%	5%	1%	0%	100%	24%	1%	21 898	1 158
Rwanda	25 206	90%	2%	7%	1%	0%	0%	100%	8%	0%	196	-
Senegal	196 761	69%	25%	6%	0%	0%	0%	100%	6%	0%	1 229	-
Sierra Leone	72 322	82%	17%	1%	0%	0%	0%	100%	1%	0%	77	-
Somalia	633 217	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
South Africa	1 220 394	78%	8%	9%	4%	1%	0%	100%	14%	1%	17 319	919
Sudan	2 503 827	80%	11%	5%	3%	0%	0%	100%	9%	0%	22 115	475
Swaziland	17 289	50%	38%	10%	2%	0%	0%	100%	12%	0%	210	-
Tanzania	941 758	74%	6%	10%	8%	1%	0%	100%	20%	1%	18 395	1 213
Togo	57 038	40%	20%	38%	2%	0%	0%	100%	40%	0%	2 280	19
Tunisia	155 176	99%	1%	0%	0%	0%	0%	100%	0%	0%	-	-
Uganda	241 278	71%	8%	14%	7%	0%	0%	100%	22%	0%	5 200	99
Zambia	751 315	100%	0%	0%	0%	0%	0%	100%	0%	0%	-	-
Zimbabwe	390 649	72%	3%	13%	11%	0%	0%	100%	25%	1%	9 885	279

Note: Restriction criteria include protected areas, wetlands, forests and agricultural areas; percentage values represent land area shares based on total country area.

Appendix D – Data Collection

Data Sources and Description

The following section describes data sources and formats used in our renewable energy potential assessment. This includes energy resources data for solar, wind and bioenergy production as well all other geographic data used to develop geographic exclusion maps (including digital elevation data, land cover data and administrative boundaries. All data are collected in GIS-readable formats (raster-based maps or referenced geographic information).

For our specific work, the spatial resolution played a critical role as data can always be generalised to a smaller scale – but the resulting values may nevertheless inherit errors as local irregularities and specificities are not captured and thus are lost in the process. As a general observation, it must be stated that the quality of the results depends on map layer with least quality and accuracy.

In our approach two main methodological sources of influence on the results can be characterised: data and processing of the resource maps (solar irradiation and wind speed) and the development of restriction areas and zones.

The resource maps used need to be validated to ensure that values correspond to real-live measurements. The error between the mapped values and on-the-ground observations is directly imported into the approach without any correction mechanism and should therefore be used with caution and compared with local data.

The restriction areas are developed from publically available and largely validated GIS maps. Nevertheless the creation of the exclusion zones is prone to inaccuracies due to the different spatial resolutions of the input layers, meaning that "coarse" input layers supersede and override the detail of high-resolution maps.

All of the above has a direct influence on results and therefore needs to be made transparent during the data development and production of results.

Solar Data

Solar irradiation data are available from a number of sources and in a number of formats but are generally not available as high-resolution data (for solar irradiation data see SWERA[1]).

The solar irradiation data used in our analysis come from the *HelioClim*[2] database and were provided by *ParisTech.*[3]

HelioClim data are derived using the Heliosat method, which converts images acquired by meteorological geostationary satellites into data and maps of solar radiation received at ground level.

The relevant data come from HelioClim-3 (2004-2010) with a step (raster size) of 0.25° (equal to about 28 km at the equator). The maps were provided by the "Centre Energétique et Procédés (CEP)" at MINES ParisTech in ESRI ASCII GRID[4] format. They contain average data (between 2004 and 2010) of the annual amount of radiation (GHI and DNI) in kWh/m^2/year. Figure 11 gives an illustration of the solar irradiation data used.

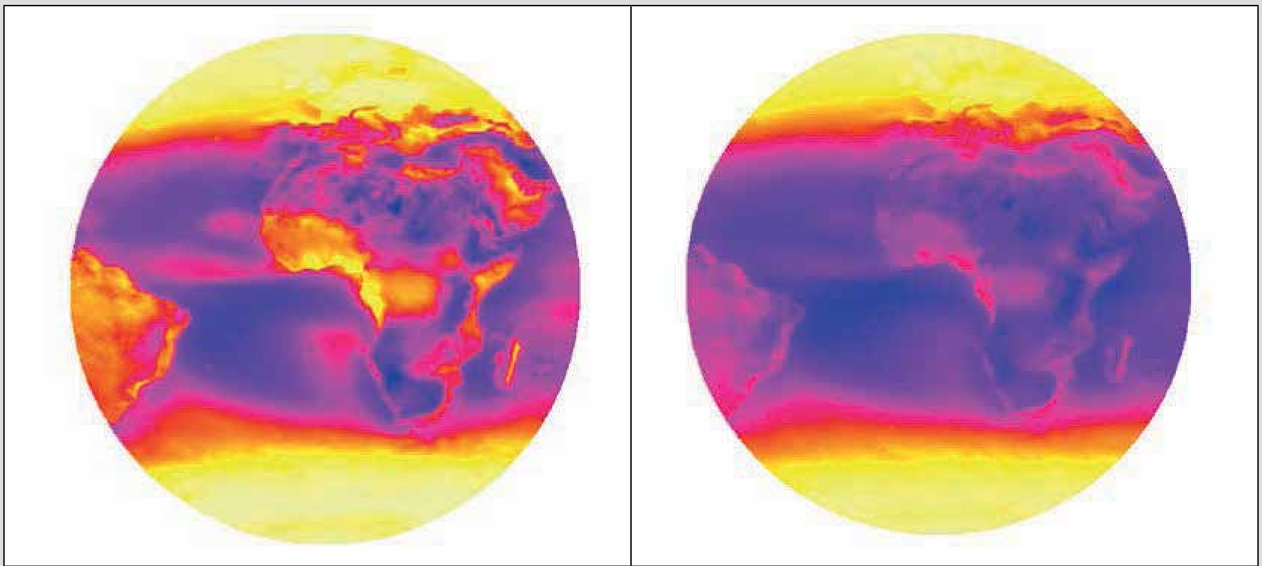
1 *Solar and Wind Energy Resource Assessment by UNEP: http://www.unep.org/climatechange/mitigation/RenewableEnergy/Activities/SWERA/tabid/29463/Default.aspx*

2 *Please see http://www.helioclim.org/ and http://www.soda-is.com/eng/map/maps_for_free.html*

3 *Paris Institute of Technology: http://www.paristech.fr/*

4 *An ESRI grid is a raster GIS file format developed by ESRI, usable with GIS software tools.*

Figure 15: Illustration of solar irradiation input data



DNI	GHI

Note: Darker, more violet areas indicate higher radiation levels.

Source: HelioClim

Wind Data

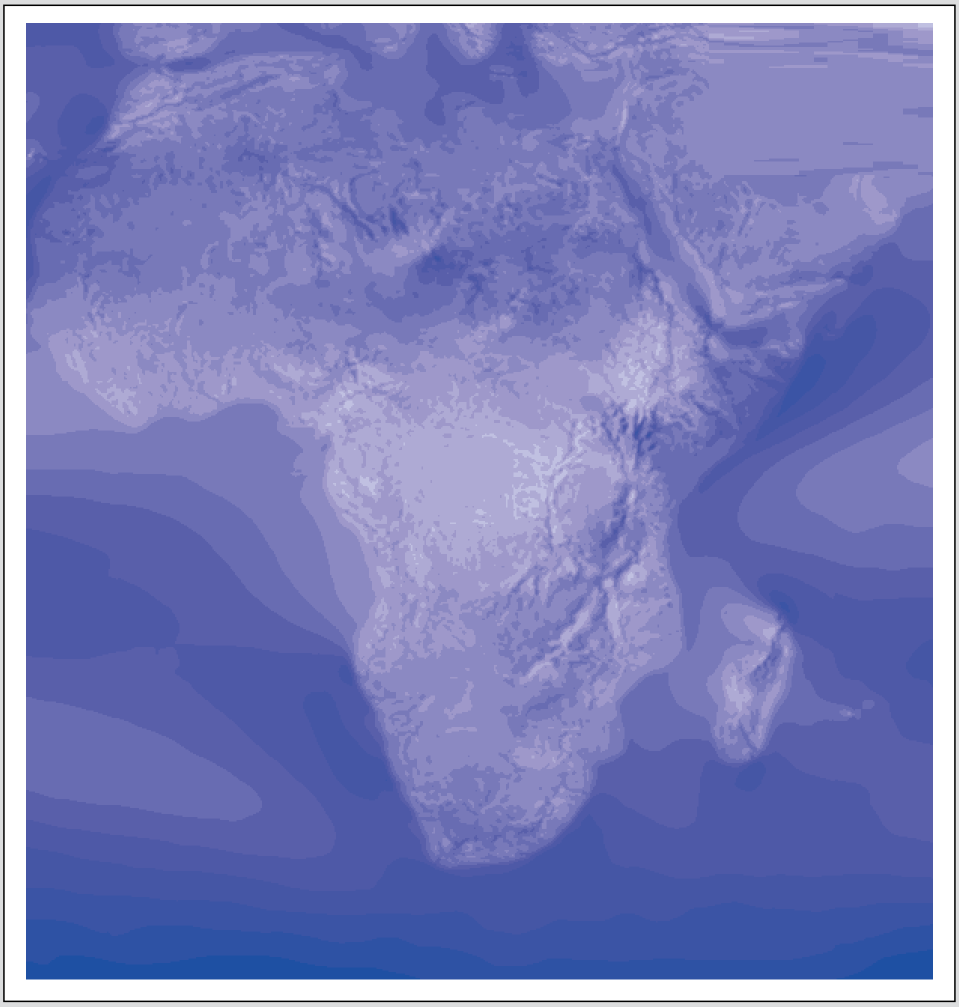
Wind data were made available for this study by VORTEX,[1] which provided us with a high-resolution "annual wind-speed map" of the African continent with a grid size of approximately 9 km, or 0.1°. Figure 12 gives an illustration of the wind data used. Wind speed was provided for a height of 80m above ground. The VORTEX data are not ground validated and therefore have limits in their large-scale applicability. Furthermore it needs to emphasised that the data are restricted and not under public domain/availability. Alternative sources for non-commercial wind data are SWERA project[2] and NASA/SSE[3] (but only at a coarse resolution of 100km grid cell size).

1 *http://www.vortex.es/*

2 *Solar and Wind Energy Resource Assessment by UNEP: http://www.unep.org/climatechange/mitigation/RenewableEnergy/Activities/SWERA/tabid/29463/Default.aspx*

3 *Surface meteorology and Solar Energy database: http://eosweb.larc.nasa.gov/sse/*

Figure 16: Illustration of average wind speed data for Africa



Source: VORTEX

Note: Darker colours indicate higher wind speeds

Bioenergy Production Data

All calculations of the potential of bioenergy sources on the continent are based on the Global Agro-Ecological Zoning model (GAEZ) developed by IIASA and FAO. A vast and freely available database of GAEZ data (in the form of results tables but also GIS data) is available at: http://www.fao.org/nr/gaez/en/ and: http://www.gaez.iiasa.ac.at/. Extensive documentation is provided in (IIASA & FAO 2012; Fischer *et al*. 2011).

The GAEZ is a well established and documented GIS-based model making it possible to show regional patterns and identify most suitable countries and regions for certain types of crops. The tool includes a vast database of agro-climatic and geographic data which are combined to build the base to predict the suitability of certain land areas for growing specific crops. Data and methodology are freely available under the FAO and IIASA GAEZ portal[1] (IIASA & FAO 2012). Reproduction of results is encouraged.

In addition to looking at the potential under current climatic conditions, the GAEZ model enables the user to look into potential climate change scenarios and predict future changes in crop production – for Africa most of the future predictions tend to show a decrease in production capacity, making implementation of biofuels as a long-term strategy even more complex.

[1] GAEZ data portals are available at FAO (http://www.fao.org/nr/gaez/en/) and IIASA (http://www.gaez.iiasa.ac.at/). Both portals provide free access to downloadable GIS raster data, including many agrological indicators and crop production values.

Administrative Country Data

Freely available country boundaries data for Africa (Source: UNSALB, http://www.unsalb.org/) were used in order to define country areas. Data include exact boundary locations as well as country sizes and population levels. Alternative data on administrative areas and boundaries can be found here in the Global Administrative Areas database (GDAM).[1]

Digital Elevation and Slope Data

Digital elevation and slope data were used to define certain land areas that are excluded from our analysis – exclusion parameters include a certain height over sea level but also steep slopes which make the application of large-scale installations impossible.

Digital elevation data are extracted from so-called digital elevation models, which offer a 3D-representation of a terrain's surface.

Freely available digital elevation data from CGIAR[2] were also used in our analysis, as well as other freely available sources for elevation and slope data (though at lower resolution levels) in GIS format such as Global Agro Ecological Zoning Model by IIASA.[3]

Population Centres

For our analysis we also used available maps which include all population centres with more than 50 000 inhabitants. Such maps are helpful to define areas that are extremely rural and potentially not suitable for large-scale electricity production. In our analysis we created a scenario where all areas further away than 200 km from any settlement (of more than 50 000 inhabitants) were excluded.

The European Joint Research Centre provides map data on population centres as well as travel times to these centres as a measure of remoteness.[4]

Other Socioeconomic Data (for further investigation) Maps and data used are open-source available information collected at the EC Joint Research Centre "About Global Environment Monitoring Unit".[5] Data also include elevation and slope data as "distance to markets" maps.

Other potential sources for country and population data include the Socioeconomic Data and Application Centre (SEDAC).[6]

Land Cover Data and Protected Areas

Land cover data were extracted from the International Steering Committee for Global Mapping portal.[7] The data are provided in TIFF format with a world file for geo-referencing and with a 30 arc seconds resolution. Land cover is separated into 20 categories including different types of forest, shrub land, herbaceous plants, crop land, paddy fields, mangroves, wetlands, urban areas, snow/ice and water bodies.

Additional land cover maps are also available from under the name "Global Land Cover 2000".[8]

The global lakes and wetlands database[9] provides spatial information about wetlands, water bodies, rivers and other water-related land forms.

Maps of protected areas can be found at "protectedplanet.net", an initiative of UNEP and IUCN.[10]

Further Sources

Other sources for free online available geographic information and tools include (among many others) the GeoNetwork – Open Source,[11] NASA's Earth Observing Data and Information System (EOSDIS),[12] DIVA-GIS[13] and Natural Earth.[14]

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1 *http://gadm.org/*

2 *http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1*

3 *See IIASAs Global Agro-ecological zoning models under: http://webarchive.iiasa.ac.at/Research/LUC/GAEZ/index.htm and http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/global-terrain-slope-download.html?sb=7*

4 *http://bioval.jrc.ec.europa.eu/*

5 *http://bioval.jrc.ec.europa.eu/*

6 *http://sedac.ciesin.columbia.edu/gpw/global.jsp#*

7 *http://www.iscgm.org/cgi-bin/fswiki/wiki.cgi*

8 *http://bioval.jrc.ec.europa.eu/products/glc2000/products.php*

9 *http://worldwildlife.org/pages/global-lakes-and-wetlands-database*

10 *http://protectedplanet.net/*

11 *http://geonetwork-opensource.org/ GeoNetwork is a catalogue application to manage spatially referenced resources. It is used by a number of organisations to provide spatial information to the public.*

12 *https://earthdata.nasa.gov/ and http://power.larc.nasa.gov/cgi-bin/cgiwrap/solar/sse.cgi?+s01+s03#s01*

13 *http://www.diva-gis.org/Data DIVA-GIS is a free GIS software, with free spatial data by country level.*

14 *http://www.naturalearthdata.com/*

Appendix E – Definition of African Regions

Table 23: List of countries included in each region

Northern Africa[38]	Eastern Africa	Western Africa	Central Africa	Southern Africa
Algeria	Burundi	Benin	Cameroon	Angola
Egypt	Djibouti	Burkina Faso	Central African Republic	Botswana
Libya	Eritrea	Cape Verde	Chad	Lesotho
Mauritania	Ethiopia	Côte d'Ivoire	Congo	Madagascar
Morocco	Kenya	Gambia	Democratic Republic of the Congo	Malawi
Tunisia	Rwanda	Ghana	Equatorial Guinea	Mauritius
	Somalia	Guinea	Gabon	Mozambique
	Sudan	Guinea-Bissau	Sao Tome and Principe	Namibia
	Tanzania	Liberia		Reunion
	Uganda	Mali		Seychelles
		Niger		South Africa
		Nigeria		Swaziland
		Senegal		Zambia
		Sierra Leone		Zimbabwe
		Togo		

[38] *Includes data from Western Sahara. The use of Western Sahara follows United Nations practices.*

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