



IRENA
International Renewable Energy Agency



BIOMASS POTENTIAL IN AFRICA



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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.

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The mission of the German Biomass Research Centre (DBFZ) is to support the effective integration of biomass as a valuable resource for a sustainable energy supply in the context of applied scientific research - including technical, environmental, economic, social and energy economics issues along the entire chain of exploitation.

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Contents

Abbreviations 7

Executive Summary 9

1. Introduction 13

2. Literature Review 15

2.1 Approach 15

2.2 Overview of former reviews and studies analysed in the report 16

2.3 Results 18

» 2.3.1 Findings from comparisons of the studies 18

» 2.3.2 Other important driving factors 20

» 2.3.3 Results of the studies 24

2.4 Discussion 31

» 2.4.1 Area potential 31

» 2.4.2 Energy crops 32

» 2.4.3 Forestry biomass 33

» 2.4.4 Residues and waste 34

2.5 Conclusion 38

3. Summary 41

References 42

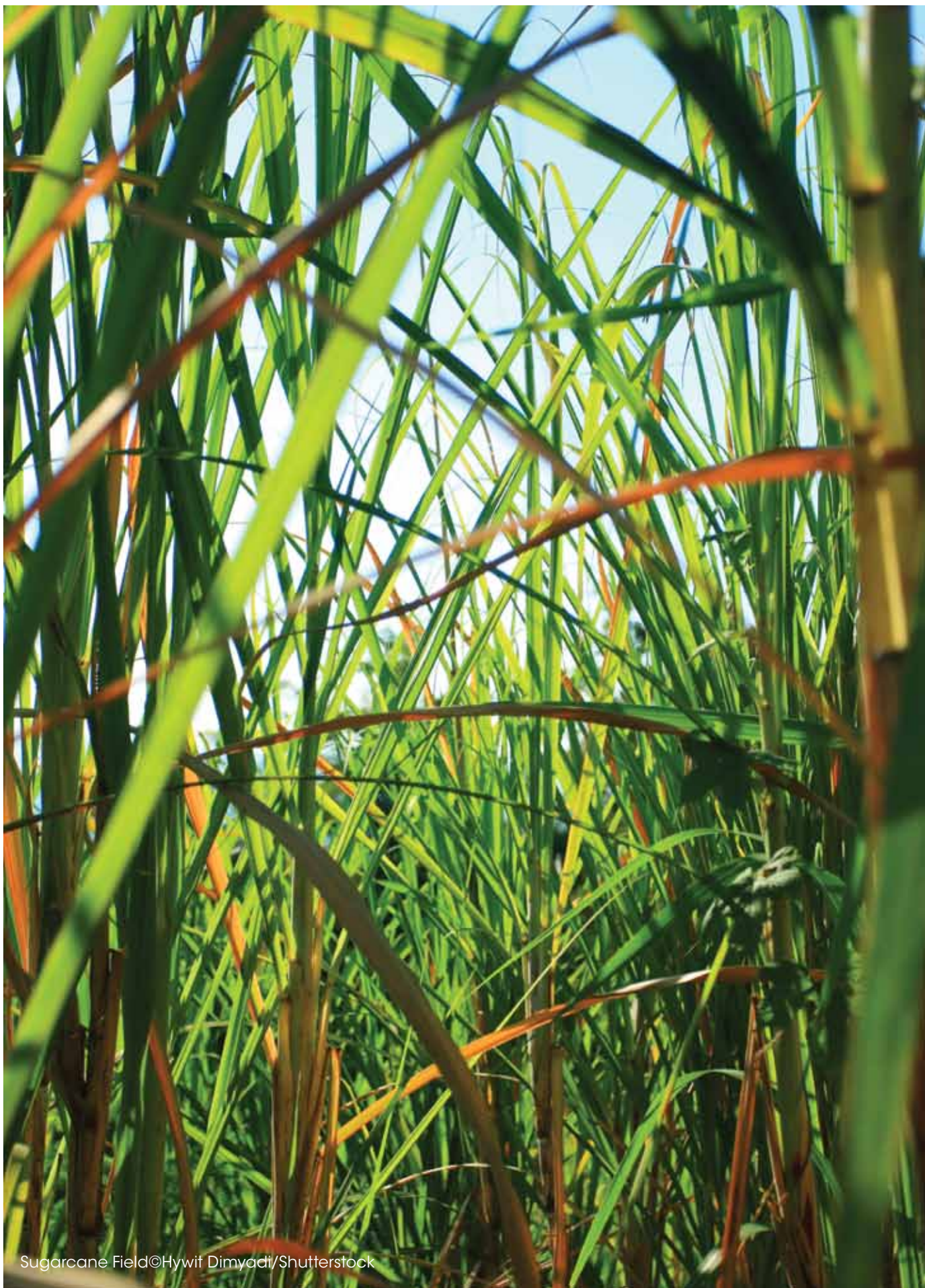


Figures

Figure 1: Based on International Energy Agency (IEA) data for 2009	10
Figure 2: Total primary energy demand for energy sources in Africa (IEA, 2010)	13
Figure 3: Structure of the analysis followed in this report	15
Figure 4: Important driving factors to consider when assessing biomass potential	20
Figure 5: Total technical biomass potential for different African regions and time periods	26
Figure 6: Area potential as dependent on time-period, African region and study	27
Figure 7: Energy crops potential as dependent on time-period, African region and study	28
Figure 8: Forestry biomass potential as dependent on time-period, African region and study	29
Figure 9: Residues and waste potential as dependent on time-period, African region and study	30

Tables

Table 1: An overview of the reviewed studies	17
Table 2: Differences in timeframe, geographical coverage and type of potential	19
Table 3: The biomass resources in each study, and its classification	21
Table 4: Other important driving factors	22
Table 5: Residue and waste biomass potential energy data for Africa (PJ/yr.)	25

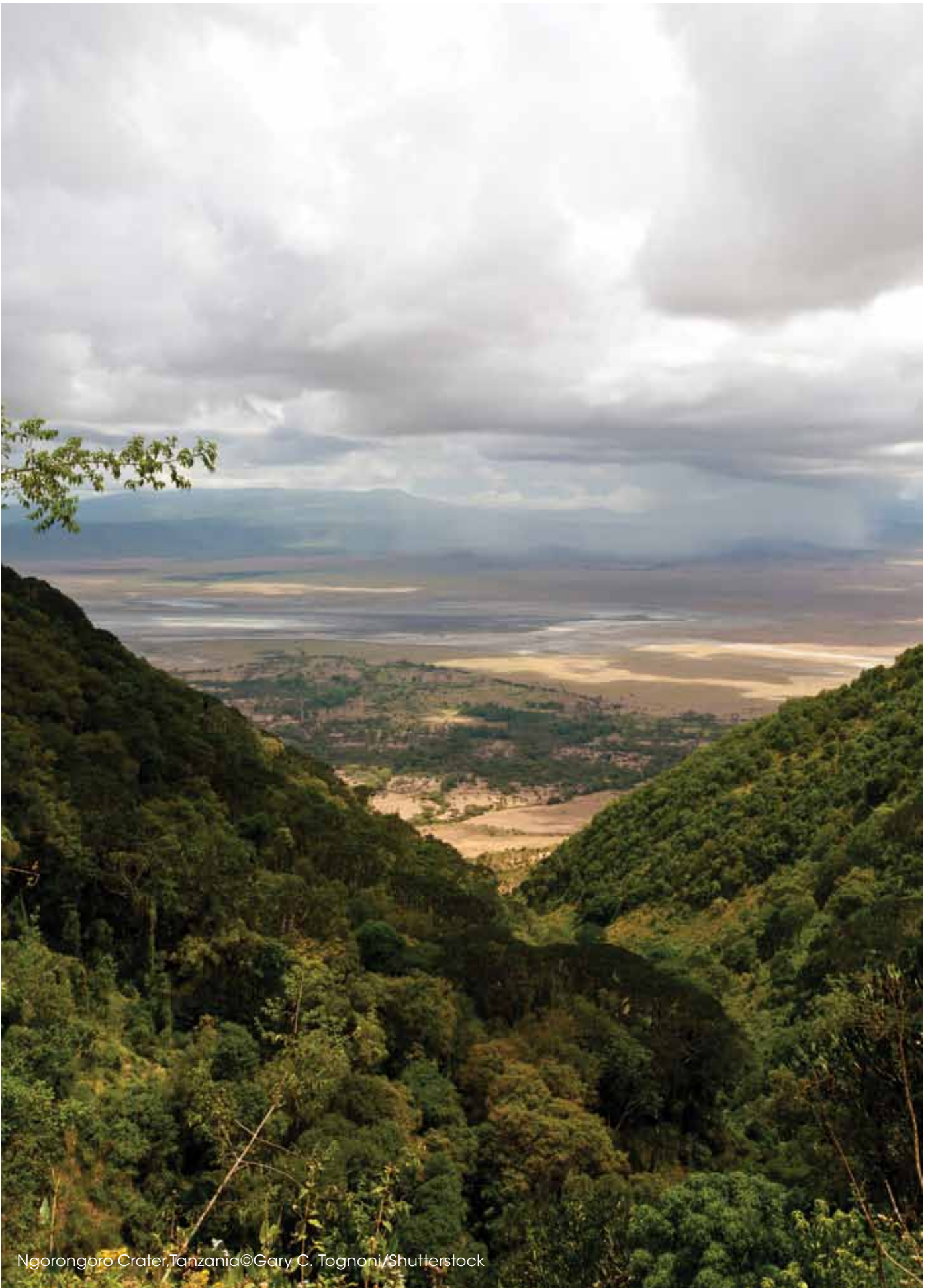


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Abbreviations

CEMA	Conference of Energy Ministers of Africa
CGPM	Crop and Grass Production Model
DBFZ	Deutsches Biomasseforschungszentrum gemeinnützige GmbH
EJ	Exajoule: 10^{18} J
EU	European Union
FAO	Food and Agriculture Organization (of the United Nations)
FRA	Global Forest Resources Assessment
GAPP	Global Agriculture Production Potential Model
GJ	Gigajoule : 10^9 J
GLC	Global Land Cover
GLUE	Global Land Use and Energy Model
ha	Hectare
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IMAGE	Integrated Model to Assess the Greenhouse Effect
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
LPJml	Lund-Potsdam-Jena managed Land Dynamic Global Vegetation and Water Balance Model
Mtoe	Million tonnes of oil equivalent
NGO	Non-Governmental Organisation
OECD	Organisation for Economic Co-operation and Development
PJ	Petajoule: 10^{15} Joule
PBL,NEAA	PBL Netherlands Environmental Assessment Agency
SRC	Short Rotation Coppice
SSA	Sub-Saharan Africa
TPES	Total Primary Energy Supply
UN	United Nations
UNDP	United Nations Development Programme
UNO	United Nations Organization
UNSD	United Nations Statistical Division
WBGU	Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen
yr	Year
Conversion factors:	1 Mtoe = 41.868 PJ = 0.041868 EJ 1 EJ = 23.88 Mtoe 1 PJ = 0.02388 Mtoe



Ngorongoro Crater, Tanzania © Gary C. Tognoni/Shutterstock

Executive Summary



Africa is currently experiencing strong economic growth and showing positive trends in human development indicators. Access to modern energy will be critical to sustain these positive signals. The continent possesses abundant renewable resources that could spur continued economic growth, accelerate social development and help the transition to a sustainable energy system that can provide universal energy access.

The African Union Assembly of Heads of State and Government in February 2009 decided to develop renewable energy resources to provide clean, reliable, affordable and environmentally friendly energy. The political will to promote renewable energy was reaffirmed in the 2010 African Union Maputo Declaration, which established the Conference of Energy Ministers of Africa (CEMA).

Ministers of energy and heads of delegations from African countries, along with the African Union Commission and CEMA, met at the invitation of the International Renewable Energy Agency (IRENA) in Abu Dhabi, United Arab Emirates, in July 2011, hosted by the UAE Government. The subsequent Communiqué on Renewable Energy for Accelerating Africa's Development, endorsed by 46 African countries and 25 African energy ministers, called for the promotion of increased utilisation of the continent's vast renewable energy resources to accelerate development. In the communiqué, the African Energy Ministers also agreed to further engage with IRENA as a key intergovernmental forum on renewable energy. They urged IRENA to provide strategic support for renewable energy in its message to the international community at Rio+20-United Nations Conference on Sustainable Development.

African countries seek to attract large investments in renewable energy technologies. A thorough planning phase is necessary to estimate the energy share that can

be supplied by renewable energy sources; to compare energy costs with that of conventional solutions; and to identify the most effective technologies that are adaptable to local conditions. This enables countries to develop adequate policy frameworks and financing instruments, to nurture human capacity and to create the necessary infrastructure to fulfil their sustainable energy aspirations.

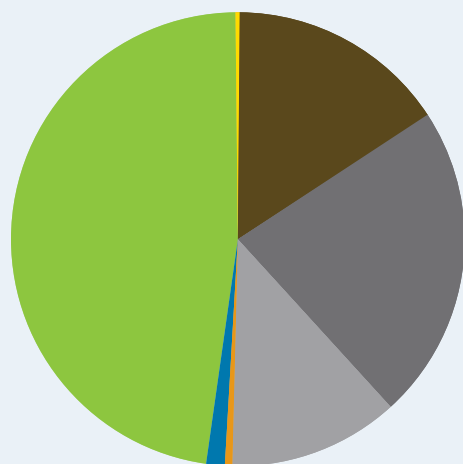
For countries to properly analyse and plan the use of renewable energy, they need accurate and documented estimates of their renewable energy potential, as well as to identify the most suitable locations for investment and deployment in renewable energy technologies. The accuracy of this information correlates directly with the risk taken in the decision-making process. Accurate data strengthens each country's national strategy to deploy renewable energy technologies.

Performing an accurate estimate of the potential requires a high level of technical knowledge, extensive consultations and large upfront investments in measurement campaigns. This situation is set to improve as IRENA increasingly provides free information and tools to assess the renewable energy potential within a country. The recent release of the solar and wind component of the Global Renewable Energy Atlas, intended to expand to other resources, has initiated a valuable process of knowledge-sharing among countries and expert institutions on renewable energy resource data.

In the meantime, however, no detailed standard methodology exists to estimate the theoretical, technical, and economic potential for renewable energy development. An analysis of the available literature on each renewable energy resource finds discrepancies in the definitions used, even for fundamental terms such as "renewable" and "potential"¹.

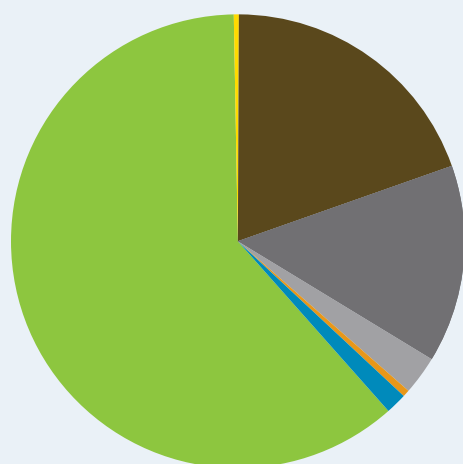
Each study in the literature investigated uses a significantly different approach to estimate renewable

¹ Available from the Global Atlas website – www.irena.org/GlobalAtlas



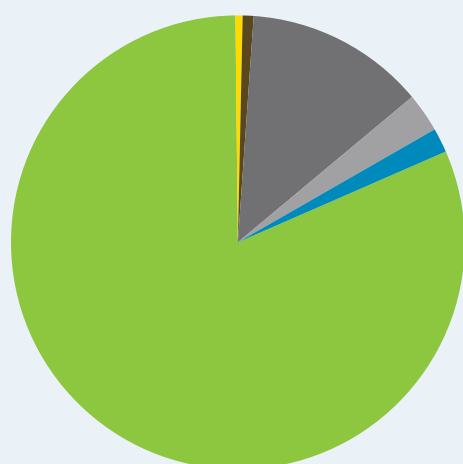
A) AFRICAN CONTINENT

Bioenergy	Shares
Solid biofuels	47.6%
Other renewables	0.2%
Coal and peat	15.7%
Oil	22.4%
Natural Gas	12.4%
Nuclear	0.5%
Hydro	1.3%



B) SUB-SAHARAN AFRICA

Bioenergy	Shares
Solid biofuels	61.2%
Other renewables	0.2%
Coal and peat	19.7%
Oil	14.1%
Natural Gas	2.7%
Nuclear	0.6%
Hydro	1.4%



C) SUB-SAHARAN AFRICA (excl. SOUTH AFRICA)

Bioenergy	Shares
Solid biofuels	81.2%
Other renewables	0.3%
Coal and peat	1.0%
Oil	13%
Natural Gas	2.7%
Hydro	1.9%

Figure 1: Based on International Energy Agency (IEA) data for 2009. The charts show the shares of bioenergy in the total primary energy supply. (A) African continent. TPES: 673 Mtoe (28 177 PJ). (B) Sub-saharan Africa. TPES: 517 Mtoe (21 646 PJ) (77% of African TPES). (C) Sub-saharan Africa, excl. South Africa. TPES: 372 Mtoe (15 575 PJ) (55% of African TPES. 72% of Sub-saharan TPES)



energy potential. With variations in the input datasets and the main parameters considered, the results of the various analyses are hardly comparable. Consequently, decision-makers are faced with a number of assessments, all of which use different methods and provide diverse results. There is a need for clarity on the key factors decision-makers must consider about renewable energy. IRENA, with its ability to convene countries and stakeholders in the field, is well placed to help determine suitable methods and the best practices to follow.

This report focuses on bioenergy in Africa, as this form of renewable energy represents almost 50% of the total primary energy supply (TPES) for the African continent (International Energy Agency (IEA), 2009a), and more than 60% of the Sub-Saharan TPES. Bioenergy is a strategic asset for Africa's energy future and needs to be assessed in a transparent manner (Figure 1).

At IRENA's behest, the German Biomass Research Centre (Deutsches Biomasseforschungszentrum gGmbH - DBFZ) has collected recent studies assessing bioenergy potential in Africa, compared their various methodologies, benchmarked the results, and identified the key dimensioning elements for those assessments. The outcomes of the analysis are as follows:

- » 1. The studies show an enormous range of calculated biomass potentials;
- » 2. The calculated area potential for energy crops ranges between 1.5 million hectares (ha) and 150 million ha;
- » 3. The various assessments indicate a potential for energy crops from 0 PJ/yr to 13 900 PJ/yr, between 0 PJ/yr and 5 400 PJ/yr for forestry biomass and 10 PJ/yr to 5 254 PJ/yr for residues and waste in Africa by 2020;

- » 4. Significant variations found between the studies are primarily due to the selected timeframe, the geographical coverage, the type of potential and biomass resources analysed. Other important reasons for deviations are the underlying assumptions, the so-called driving factors, and the accuracy of the input databases;
- » 5. All the biomass calculations from today through to the year 2100 show a considerable range in potential. For the year 2050, a potential range between 2 360PJ/yr and 337 000 PJ/yr is revealed for Africa (energy crops: 0 PJ/yr to 317 000 PJ/yr; forestry biomass: 14 820 PJ/yr to 18 810 PJ/yr; residues and waste: 2 190 PJ/yr to 20 000 PJ/yr). The potentials for the year 2100 determined in two studies, vary between 74 000 PJ/yr and 181 000 PJ/yr;
- » 6. The calculated area potentials and the assumed production yields have a significant impact on the potential amount of energy crops, forestry biomass, and residues and waste that are available for energy provision;
- » 7. In the studies, both the area potentials and production yields are analysed at different levels of detail and found generally to have a high degree of uncertainty;
- » 8. A precondition for achieving high energy crop potential is an increase in productivity to a level similar to that of industrialised countries, or a stronger focus on energy crop production, e.g. through the cultivation of energy crop rotations;
- » 9. In contrast studies showing little or no potential of energy crops in Africa assume that the enormous population growth and the associated increase in per capita consumption – especially of animal products – will prevent an energy-related use of biomass;
- » 10. One of the key parameters to determine the potential of forestry biomass, or residues and waste, is the competitive use of materials;
- » 11. In general, climate change impacts, biodiversity and social criteria, e.g. land ownership, remain insufficiently considered in the studies reviewed;
- » 12. A large problem in determining biomass potentials for Africa is the poor data availability. Inaccurate and obsolete databases often provide

the initial values for the estimations of the current and future potentials.

Due to the large range in results presented by the reviewed studies, no definite figures regarding the availability of biomass in Africa can be provided. Any analysis based on these studies needs to account for their underlying assumptions. The existing data, methodological approach and results, can however be used to identify areas for further research.

This report is a first step towards bringing clarity to decision makers on the information available on bioenergy potentials. By understanding the discrepancies between the existing approaches and visualising the variability of results between the different methods, decision makers can evaluate the impact different assessments can have on their strategic decisions.

This report highlights the need for developing recommendations and standard methods to provide accurate estimates of bioenergy potentials.

Bioenergy resource assessment is a particularly complex subject. The assessment needs to factor possible conflicts with other land uses, forecast increases in agricultural productivity, and project food demand over time (Belward, et al., 2011). Since the assessment is extremely sensitive to the local context and political choices, assessing the bioenergy potentials is a country-driven exercise.

The Global Renewable Energy Atlas initiative began by offering free and open access to data on wind and solar energy. IRENA will progressively expand this initiative, with the objective of providing relevant information, access to datasets and tools for decision-makers to assess all types of renewable energy potential, including biomass. IRENA will continue to work with the bioenergy community to identify the relevant information, methods and tools that can help countries wanting to assess their national potential for biomass development in detail.

1. Introduction



Bioenergy is currently the primary energy resource for about 2.7 billion people worldwide (Wicke, *et al.*, 2011), playing a traditional role in Africa. The total primary energy demand (TPED) for Africa is predominantly determined by biomass demand (Figure 2), with almost half of the energy demand (47.9%) being covered by biomass and waste. The International Energy Agency (IEA) projects a decline in the total energy share of biomass and wastes by 2035², but biomass will still continue to remain an important energy resource for Africa in the future (IEA, 2010).

As well as the TPED, the total final consumption (TFC) for Africa is also predominately composed of biomass and wastes. The IEA estimates that the total final

consumption biomass/waste share will lie between 51% and 57% by 2035 depending on which scenarios are assumed (IEA, 2010). However, there are enormous regional differences within Africa. Particularly those countries characterised by high poverty, the proportion of biomass is much higher. In some countries, such as Burundi, Rwanda and the Central African Republic, the energy provision from biomass is 90% or greater (Dasappa, 2011). In Sub-Saharan Africa (SSA) people are more dependent on 'traditional' biomass energy compared to other regions (Eleri and Eleri, 2009). In this report traditional biomass refers to the unsuitable use of fuel wood, charcoal, tree leaves, animal dung and agricultural residues for cooking, lighting and space heating. In comparison to a modern use of biomass, which normally includes an effective technical utilisation

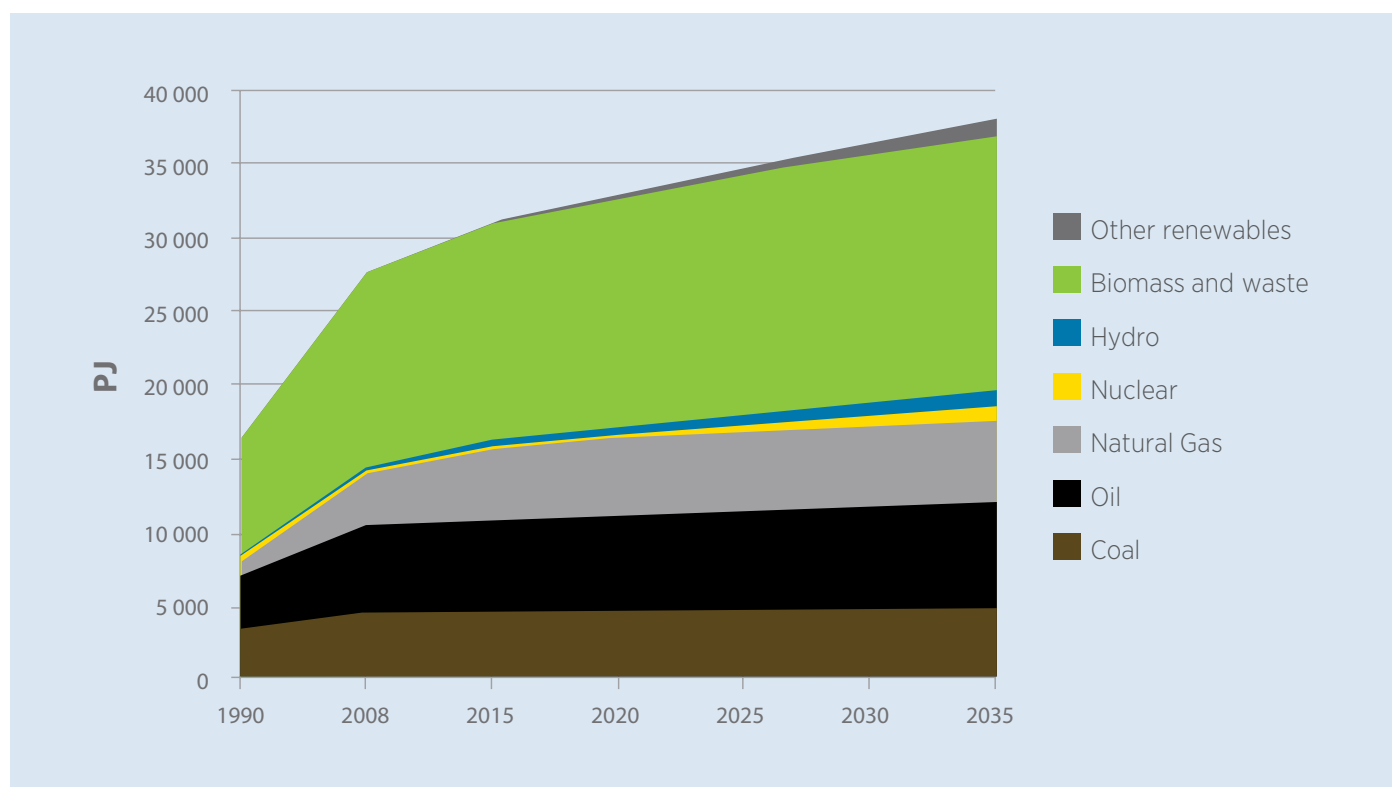
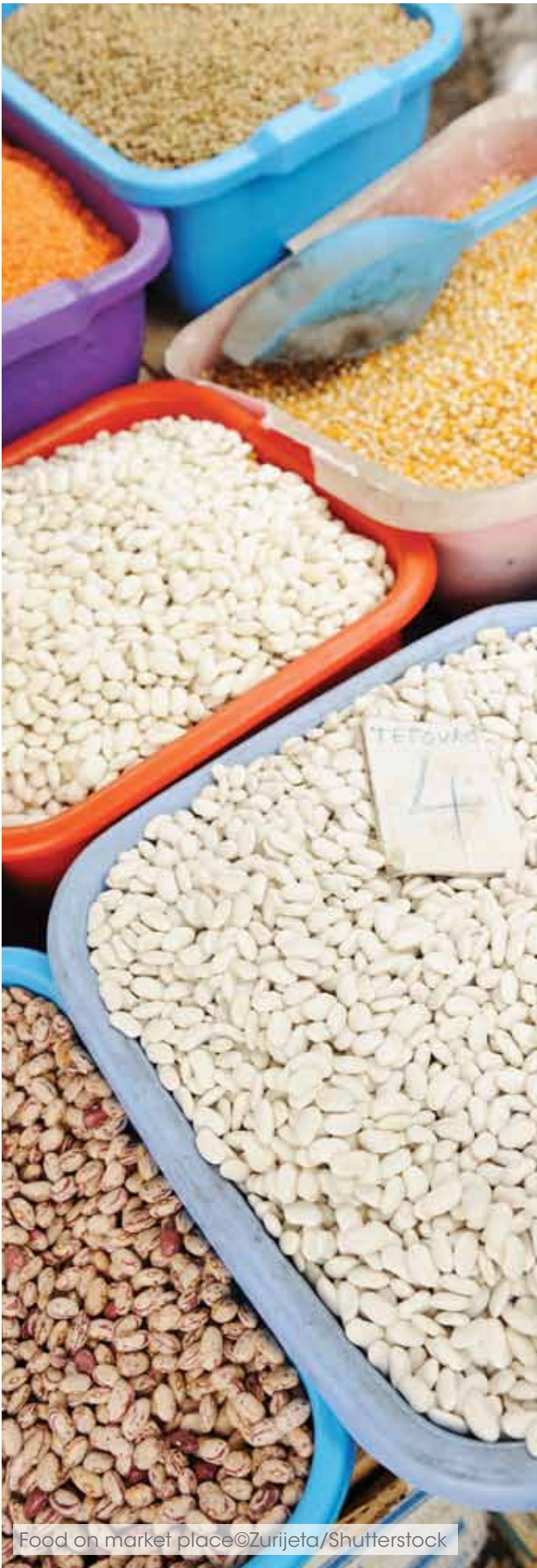


Figure 2: Total primary energy demand for energy sources in Africa (IEA, 2010)

² The projections are based on the 'New policies scenario'. This scenario "takes account of the broad policy commitments and plans that are announced by countries around the world, to tackle either environmental or energy security concerns, even where the measures to implement these commitments have yet to be identified or announced" (IEA, 2010).



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to produce energy efficiently, traditional biomass is used with very low energy efficiencies. Moreover, traditional biomass use can have serious negative impacts on health and living conditions, e.g. pneumonia, chronic obstructive pulmonary diseases or lung cancer (IEA, 2009b; Chum, *et al.*, 2011; Legros, *et al.*, 2009).

Despite an increase in energy use, many poor households in Africa have no access to modern energy sources. Worldwide, SSA and India have the greatest proportion of population dependent on traditional biomass use. In Africa, a total of 657 million people (80% of the population) rely on the traditional use of biomass for cooking (IEA, 2010). It is important given this scale of biomass use that modern bioenergy systems are able to provide an important contribution to future energy systems and to the development of sustainable energy supplies (Berndes, Hoogwijk and Broek, 2003).

It is therefore crucial to use the potential renewable energy resources effectively. In addition, against the background of food security, if biomass energy is developed in a sustainable manner, this creates opportunities for increased food production, especially in rural areas (Eleri and Eleri, 2009).

In general, the availability and quality of biomass energy data in Africa is scarce. There are some country-specific studies, as well as various international research projects that focus on the estimation of global biomass potentials, which provide some information about Africa. Although a few publications engage with this field of research, there is no scientific literature review for Africa to date.

It is important that in making statements about the prospects for development of sustainable bioenergy from biomass sources in Africa, that a realistic order of magnitude for biomass potentials is assessed. This project report aims to provide an overview and comparison of the available studies relating to biomass potentials in Africa. The considerable discrepancies among the studies' results will be illustrated and explained, and the requirements concerned with determining parameters and the other challenges associated with potential estimates will be discussed.

This report contains an overview of the selected studies. The findings are presented and discussed; they concern the methodology and analysis of results for different biomass categories, including the uncertainties in the database and the broad deviations of the study results. The report closes with conclusions and remarks.

2. Literature Review



2.1 APPROACH

The approach in this study (Figure 3) first evaluates existing literature reviews on global biomass potentials. In particular, attention is given to those biomass studies published after 2005 that have included information about Africa. The number of studies found within this timeframe is small and the search expanded to include those studies published after 2000. Additional studies focus on specific African countries. By including some country-specific studies it became possible to compare the national biomass potentials and to make comparisons with larger-scale continental and global studies. A total of 14 studies are used for the analysis.

The study analysis is divided in two sections (Figure 3). In the first section, the methodology and assumptions used in the selected studies are analysed. To enable a comparison, several criteria are established, which include the definition

of the biomass potential, the timeframe, the geographic coverage and the underlying biomass resources considered in the studies. Another criteria used to compare studies is the group of “other important driving factors”, which combines all parameters that impacted on the amount of biomass potential. These parameters are both listed and classified in a database, with special attention paid to their source and data quality.

In the second section of the analysis, study results and declared potentials are evaluated, creating a comparative basis where the results are grouped by the four categories: available land for energy production; energy crops; forestry biomass; and residues and waste.

The discussion identified the main causes for discrepancies in the results. All results from the four biomass potential categories are discussed, and the main parameters compared. The question of where to focus further research is highlighted in the conclusion.

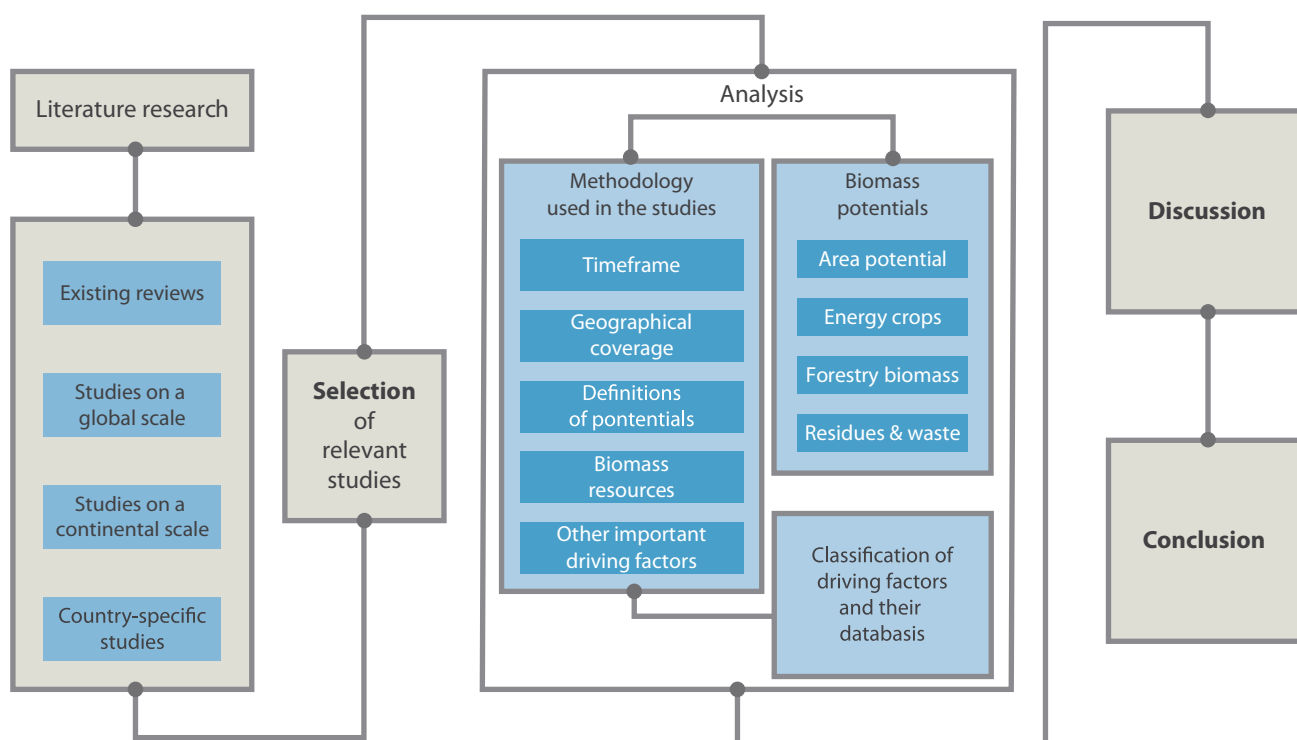


Figure 3: Structure of the analysis followed in this report

2.2 OVERVIEW OF FORMER REVIEWS AND STUDIES ANALYSED IN THE REPORT

Three literature reviews are presented hereunder, comparing different methodologies used to assess global biomass potentials, the final results found and the input databases used.

In Berndes, Hoogwijk and Broek (2003), 17 studies are analysed. The conclusions of the reviewed studies are discussed with regard to the underlying assumptions and methodology (timeframe, geographical aggregation and bioenergy resources).

Moreover, the review concentrates on the classification of studies in demand-driven³ and resource-focused⁴ assessments. The possible contribution of biomass to future global energy supply ranges from below 100 exajoules per year (EJ/yr) to over 400 EJ/yr by 2050. As a matter of comparison, the global energy demand in 2010 reached 12 380 Mtoe in 2010, equivalent to 518 EJ (IEA, 2012).

Most of the studies consider biomass plantations as the most important source of biomass for energy (e.g. biomass plantation supply is forecast to be between 47 EJ/yr and 238 EJ/yr by the year 2050). Berndes, Hoogwijk and Broek (2003), found two major parameters explaining the discrepancies among the literature reviewed: land availability; and yield levels in energy crop production. Both parameters although uncertain, are crucial to estimating future biomass potentials.

In a comparison of 19 studies by Thrän, *et al.* (2010a), there was found to be a large range in results for biomass fractions of energy crops, organic residues and waste. The largest difference between the results in this literature review is found in the potential of energy crops. While some studies indicate an energy crop potential of 0 EJ/yr by 2050, optimistic estimations of values reach 1 272 EJ/yr for this time period. The global potential of forest residues ranges from 0 EJ/yr to 150 EJ/yr in 2050. In addition to analysing results, Thrän, *et*

al. (2010a) highlights the dominant influencing factors on the amount of biomass potential, with the most important being global population growth; followed by future per capita consumption and development of specific yields for food, including fodder and biomass production (Thrän, *et al.*, 2010a).

The third literature review, by Chum, *et al.*, (2011), analyses 15 scientific studies in which global biomass potentials are calculated. Although the various factors influencing the amount of the potential are named, there is no precise specification attached to these factors. The literature review comes to the conclusion that the global potential of biomass for different categories⁵ in the studies ranges from less than 50 EJ/yr to more than 1 000 EJ/yr by 2050 (Chum, *et al.*, 2011).

All the literature reviews highlight the enormous range in global biomass potential studies. Although some reviews analyse the regional differentiation of global biomass potentials, no figures on Africa are reported, for example, Berndes, Hoogwijk and Broek (2003), distinguished between the calculated biomass potentials of developed and developing countries.

According to the estimates from most of the reviewed studies, developing countries will account for the largest share of global energy supply in the longer term (Berndes, Hoogwijk and Broek, 2003).

Fourteen studies analysed in the following section (Table 1), make more precise statements about the biomass potential in Africa. Those fourteen studies include nine global, three continental and two country-specific studies. All studies indicate numerical estimates of the biomass potentials for different biomass fractions. The exact geographical coverage for the calculated potentials can be taken from Section 2.3.1.

³ Demand-driven assessments analyse the competitiveness of biomass-based electricity and biofuels, or estimates of the required biomass to meet exogenous targets for a climate-neutral energy supply (demand side) (Berndes, Hoogwijk and Broek, 2003).

⁴ In resource-focused assessments the total bioenergy resource base and the competition between different resource uses (supply side) are analysed (Berndes, Hoogwijk and Broek, 2003).

⁵ The categories include residues from agriculture (15 EJ/yr to 70 EJ/yr.), dedicated biomass production on surplus agricultural land (0 EJ/yr to 700 EJ/yr.), dedicated biomass production on marginal lands (0 EJ/yr to 110 EJ/yr.), forest biomass (0 EJ/yr to 110 EJ/yr.), dung (5 EJ/yr to 50 EJ/yr.) and organic waste (5 EJ/yr to over 50 EJ/yr.).

Table 1: An overview of the reviewed studies.

Acronym ⁶	Reference
BATIDZIRAI	Batidzirai, B., A.P.C. Faaij and E.Smeets (2006), "Biomass and bioenergy supply from Mozambique", <i>Energy for Sustainable Development</i> , Vol. 10, No. 1, pp. 54-81 (doi:10.1016/S0973-0826(08)60507-4).
BMVBS	BMVBS(2010), "Globale und regionale räumliche verteilung von biomassepotenzialen - status quo und möglichkeit der präzisierung; Endbericht", BMVBS-Online-Publikation, (www.bbsr.bund.de/cIn_032/nn_629248/BBSR/DE/Veroeffentlichungen/BMVBS/Online/2010/DL__ON272010,templateld=raw,property=publicationFile.pdf/DL_ON272010.pdf).
COOPER	Cooper, C.J. and C.A. Laing (2007), "A macro analysis of crop residue and animal wastes as a potential energy source in Africa", <i>Journal of Energy in Southern Africa</i> , Vol. 18, No. 1, pp. 10-19.
DASAPPA	Dasappa, S. (2011), "Potential of biomass energy for electricity generation in Sub-Saharan Africa", <i>Energy for Sustainable Development</i> , Vol. 15, No. 3, pp. 203-213 (doi:10.1016/j.esd.2011.07.006).
DUKU	Duku, M.H., S. Gu, and E.B. Hagan (2011), "A comprehensive review of biomass resources and biofuels potential in Ghana", <i>Renewable and Sustainable Energy Reviews</i> , Vol. 15, No. 1, pp. 404-415.
FISCHER	Fischer, G. and L. Schrattenholzer (2001), "Global bioenergy potentials through 2050", <i>Biomass and Bioenergy</i> , Vol. 20, No. 3, pp. 151-159, (doi:10.1016/S0961-9534(00)00074-X).
HABERL	Haberl, H., <i>et al.</i> (2011), "Global bioenergy potentials from agricultural land in 2050: Sensitivity to climate change, diets and yields", <i>Biomass and Bioenergy</i> , Vol. 35, No. 12, pp. 4753-4769 (doi:10.1016/j.biombioe.2011.04.035).
HAKALA	Hakala, K., Kontturi, M., and Pahkala, K (2009), "Field of biomass as global energy source", <i>Agricultural and Food Science</i> , Vol. 18, No. 3-4, pp. 347-365.
HOOGWJK	Hoogwijk, M. (2004), On the global and regional potential of renewable energy sources, PhD Thesis, Utrecht University, Utrecht.
KALTSCHMITT	Kaltschmitt, M.,H. Hartmann, and H. Hofbauer (2009), "Energie aus biomasse: grundlagen, techniken und verfahren", Springer, pp 1032 (ISBN: 9783540850946).
SMEETS	Smeets, E.M.W., <i>et al.</i> (2007), "A bottom-up assessment and review of global bio-energy potentials to 2050", <i>Progress in Energy and Combustion Science</i> , Vol. 33, No. 1, pp. 56-106 (doi:10.1016/j.pecs.2006.08.001).
WEC	World Energy Council (2010), "2010 Survey of energy resources", London, pp. 618, www.worldenergy.org/publications/3040.asp
WICKE	Wicke, B., <i>et al.</i> (2011), "The current bioenergy production potential of semi-arid and arid regions in sub-Saharan Africa", <i>Biomass and Bioenergy</i> , Vol. 35, No. 7, pp. 2773-2786 (doi:10.1016/j.biombioe.2011.03.010).
YAMAMOTO	Yamamoto, H., J. Fujino, and K. Yamaji (2001), "Evaluation of bioenergy potential with a multi-regional global-land-use-and-energy model", <i>Biomass and Bioenergy</i> , Vol. 21, No. 3, pp. 185-203 (doi:10.1016/S0961-9534(01)00025-3).

⁶ Acronyms are used in Table 1 to distinguish those studies from the literature references made throughout this report.

2.3 RESULTS

The substantial differences found between the studies are due to complex reasons. The main differences between the various methodologies and assumptions used are:

- » Timeframe
- » Geographical coverage
- » Definition of potential
- » Biomass resources
- » Other important driving factors

Section 2.3.1 includes all results from the calculated potentials in the reviewed studies. The biomass potentials are classified into the following categories: area potential and energy crops, forestry biomass, and residues and waste.

2.3.1 Findings from comparisons of the studies

The first significant difference between the studies is the selected timeframe (Table 2). The majority of the studies show values for the present-day situation. In order to project future energy potentials in Africa, most studies calculate up to the year 2050. Very little information is available for the short- and mid-term forecasts (2020-2030), or for the longer-term (year 2100). In the studies, various parameters such as future food and feed demand, yields from crop species, environmental issues, etc. (see section 2.3.2) are taken into account. Their significance in assessing the future biomass potential depends strongly on the time period selected.

Secondly, the studies differ in the geographical area covered. With the exception of country-specific studies, all other studies calculate and summarise biomass potentials for a number of African countries that are then referred to as overall Africa or SSA (Table 2). In the SSA studies, the analysis of potentials in North Africa is combined with West Asia, Middle East or Near East. This geographical delimitation means it is not possible to use these studies to make a statement on the potential for the whole of the African continent. Furthermore, the studies also varied in the number of countries considered, if this value was given at all. These variations in area need

to be considered when interpreting the results of the studies.

Thirdly, the heterogeneous use of the term “potential” in the studies differs, but can generally be distinguished as theoretical, technical or economic potential.

The theoretical potential describes the theoretical maximum energy supply that is physically available in a given region within a specified period of time, (e.g. energy saved in the entire crop mass). It is determined by its limits of physical utilisation and therefore is the upper limit to the provision of energy that can be theoretically realised. As not all of the theoretical energy potential can be realised it is of no practical relevance in assessments of actual biomass availability.

The technical potential describes the theoretical potential that can be used after accounting for energy losses through the technical conversion process. The calculation of the technical potential often includes the structural, ecological, administrative and social limitations as well as legal requirements, since they ultimately can be regarded as “insurmountable”, in a way that is similar to the technically determined limitations.

The economic potential is the share of the technical potential which is economically profitable in given conditions (Rettenmaier, *et al.*, 2008).

To clarify further the available level of potential, additional terms are used besides the theoretical, technical and economic potential. For example, the implementation potential describes the actual contribution to energy supply. This potential depends on a variety of other socio-political and practical constraints (Thrän, *et al.*, 2010b). An estimation of the implementation potential can only be assessed at a regional level, requiring an enormous effort, because of the number of restrictions that have to be taken into account (e.g. considering the willingness of the biomass producers to sell the feedstock). An assessment of the implementation potential for the whole of Africa is currently not practical.

All the studies reviewed evaluate the technical potential (Table 2) and in three studies, the economic potential is also determined. Although the same term is used in the studies, the underlying assessment factors of the potentials vary considerably. Technical, structural and environmental constraints, as well as legal requirements

are accounted for as each author sets out a range of factors which manifest themselves to different extents, depending on the system boundary and the biomass fraction considered. The biomass potential is therefore not strictly defined, but is related to numerous assumptions and boundary conditions (BMVBS, 2010; Kaltschmitt, Hartmann and Hofbauer, 2009). An overview of the driving factors considered in the studies is given in Section 2.3.2.

Finally, there is no uniform classification for the description of types and fractions of biomass resources. Biomass being defined as “the biodegradable fraction of products, waste and residues from biological origin from

agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste” (European Union (EU), 2009).

To compare the amount of potentials calculated in the reviewed studies, the different biomass resources are divided into three biomass fractions:

- » Energy crops
- » Forestry biomass
- » Residues and waste

Table 2: Differences in timeframe, geographical coverage and type of potential

Acronym	Time period	Geographical coverage	Type of potential	
			Technical	Economical
BATIDZIRAI	2015	Mozambique	X	X
BMVBS	2007; 2010; 2015; 2020; 2050	Africa	X	
COOPER	Current	Africa	X	
DASAPPA	Current	SSA	X	
DUKU	Current	Ghana	X	
FISCHER	2050	SSA	X	X
HABERL	2050	SSA	X	
HAKALA	2006; 2050	Africa	X	
HOOGWJK	2050; 2100	Africa	X	
KALTSCHMITT	Current	Africa	X	
SMEETS	2050	SSA	X	
WEC	Current	Africa	X	
WICKE	Current	Botswana, Burkina Faso, Kenya, Mali, Senegal, South Africa, Tanzania, Zambia	X	X
YAMAMOTO	2100	SSA	X	

Table 3 shows the biomass resources considered in the studies and their allocation within the three biomass fractions. The resources included in Table 3 identify the biomass fractions used exclusively in the African studies. All of the studies provide an estimate of the potential for the biomass fraction from residues and waste, whereas the feedstock type is different for every study. In ten studies, the energy crop potential is determined, while the forestry biomass potential is only calculated in six of the studies.

The type of biomass found in the different biomass fractions varies greatly. While some studies calculated only the potential of a particular crop type (e.g. eucalyptus), other studies refer to a large number of crop species. Some studies fail to identify the feedstock composition or its raw materials fraction, instead providing a general description of the biomass resources (e.g. energy crops on grassland or crop residues).

Moreover, a stringent classification of feedstock is not always possible, because the biomass fractions overlap each other (e.g. forest products and wood residues). Not all studies are clear about the exact feedstock they consider, which may influence greatly the biomass potential.

2.3.2 Other important driving factors

The biomass potential is largely determined by the factors shown in Figure 4. The demand for food grows with an increasing population; and the per-capita consumption is also dependent on a country's economic development. With limited potential area, the increased demand may be offset by increases in crop yield. Otherwise, the agricultural acreage needs to expand (e.g. through deforestation) or food imports need to be increased to meet the population's demand.

These factors can all operate as driving factors that cover certain social, environmental or economic dimensions, or can be seen as restrictions that directly limit the biomass availability. The driving factors in the selected studies are determined by parameters that are considered by the authors of each study, differently.

Table 4 presents the associated databases for the driving factors used by authors in their studies. These include for example, areas of land with special protection status (e.g. biodiversity, conservation areas) that can reduce the potential area for bioenergy production, and climate change with its effect on production yields. Yields are also influenced by both economic development and agricultural productivity of a country. Besides these broader differences between the models used in the

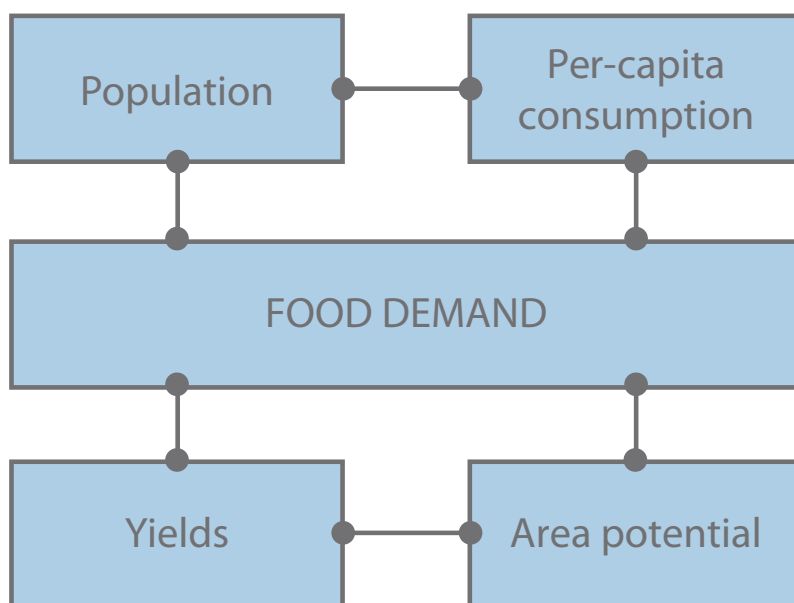


Figure 4: Important driving factors to consider when assessing biomass potential

Table 3: The biomass resources in each study, and its classification.

Acronym	Biomass fraction		
	Energy crops	Forestry biomass	Residues and waste
BATIDZIRAI	Eucalyptus		Logging residues, industrial waste, bagasse
BMVBS	Cereals, maize, rape, sunflower, soya, sugar beet, sugarcane, oil palm, grassland	Fuel-wood	Straw, municipal waste (bio-waste and wood residues), animal residues, industrial wood waste, logging residues, coconut, oil palm, bagasse
COOPER			Crop residues, animal waste, bagasse, coconut shells
DASAPPA		Fuel-wood	Crop residues, logging residues, industrial waste wood
DUKU			Crop residues, coconut, oil palm
FISCHER	Biomass (e.g. energy crops) on grassland	Forest products	Crop residues
HABERL	Energy crops on cropland and on other land (i.e. grazing land)		Residues on cropland
HAKALA	Not clarified		Crop residues
HOOGWIK	Energy crops		
KALTSCHMITT	Not clarified	Fuel-wood	Crop residues, animal residues
SMEETS	Woody energy crops (e.g. eucalyptus, willow), conventional crops (e.g. sugarcane, wheat, maize) and grasses (e.g. miscanthus)		Crop harvest residues, crop process residues, wood harvest residues, wood process residues, wood waste
WEC			Bagasse
WICKE	Atrophy, cassava, short rotation coppice		
YAMAMOTO	Not clarified	Fuel-wood	Human faeces, kitchen refuse, animal dung, harvesting residues, timber scrap, paper scrap, sawmill residues, black liquor, fuel wood/ industrial felling residues

analysis, variations occur with regard to the application and combination of data sources. Sometimes, very complex phenomena (e.g. climate change and the issue of sustainability) are excluded or not dealt with to the correct level of detail in the studies, and yet some of the reviewed studies use complex data models to simulate current and future material flows. Variations also extend to the database chosen and the time period considered, and the differences may significantly influence the extent and the range in results.

In the following box, information about the individual databases is compiled. Complex models tend to use statistical data from the FAO and other UN entities. Unfortunately there are no real alternatives to these datasets and the data quality for Africa is poor. For example, the data used from remote sensing, e.g. Global Land Cover (GLC) often has no reference to any reporting requirements from the country concerned. The GLC database was produced in 2000, and is now out of date, because of the dynamic land use in Africa.

Table 4: Other important driving factors

Driving factor	Database used
Social dimension	
Food demand - Population - Per capita consumption	United Nations Development Programme (UNDP), United Nations (UN), Global Land Use and Energy Model (GLUE), Integrated Model to Assess the Greenhouse Effect (IMAGE), International Institute for Applied Systems Analysis (IIASA), Global Agricultural Production Potential Model (GAPP) Food and Agriculture Organization (FAO), GLUE, UN, GAPP
Environmental dimension	
Biodiversity	www.biodiversityhotspots.org, Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (WBGU)
Conservation areas	World Database on Protected Areas (WDPA), GLUE
Climate change/ environmental conditions like deforestation	Lund-Potsdam-Jena managed Land Dynamic Global Vegetation and Water Balance Model (LPJml), Intergovernmental Panel on Climate Change (IPCC), WBGU, IMAGE, FAO, GLUE, Literature
Economic dimension	
Economic growth	FAO, World Bank, Quicksan Model, IMAGE
Costs (production, transport, conversion)	FAO, World Bank, Literature, Expert decision
Efficiency of agricultural production system	Crop and Grass Production Model (CGPM), IMAGE, FAO, IIASA, GLUE, IPCC, GAPP Literature
General	
Land use	Global Land Cover (GLC); FAO, GLUE, IMAGE, IIASA, GAPP, Literature
Biomass demand/material utilisation	IMAGE, GLUE, Literature

DETAILS OF THE MAJOR DATABASES USED BY THE STUDIES

FAO: The FAO is a UN specialised agency that manages a comprehensive database of reported national data. In general, data provision is based on the reporting of governments (ministries), non-governmental organisations (NGOs) or private, as well as international authorities (FAO, 2011a). The FAO Statistics Division is responsible for the management of the data pool e.g. FAO holds statistics about food, agriculture, forestry and fisheries in FAOSTAT, a statistical databases collection (FAO, 2011b). The database itself is connected with national or regional statistical information systems (e.g. CountrySTATS; FAO, 2011c). Additionally, the FAO uses databases from other international organisations, e.g. United Nations (UN) in order to carry out secondary statistical research (United Nations Statistics Division, 2011a).

UN: The United Nations Statistical Division (UNSD) performs, for example, energy statistics through national surveys within the member countries (Energy Statistics Database; UNSD, 2011). The UNSD manages the data pool of the UN (web based information systems UNDATA) and is supervised by the United Nations Statistical Commission (UNSC).

UNDP: As a member within the United Nation system, the UNDP is part of the UNO data pool. The organization also uses surveys from other international institutions, such as the Organisation for Economic Co-operation and Development (OECD), World Bank, etc. (UNDP, 2011).

GLC: The Global Land Cover, produced in 2000 provides global land use data. The data on global spatial information with a resolution of 1 km² were recorded during a 14 month period (November 1999 to December 2000) using SPOT4 satellites (European Commission, Joint Research Centre 2011).

IMAGE: This database was initiated by the Environmental Assessment Agency of the Netherlands (PBL, NEAA, 2011a). The model simulates the environmental impacts of human activities and processes demographical, technological, economic, social, cultural and political data (Bouwman, Kram and Klein Goldewijk, 2006). Secondary statistical data sources are used, including values from the World Bank, UN, FAO, etc.

IIASA: This database relates to the development of forestry and above-ground biomass, the IIASA used the results of the Global Forest Resources Assessment 2005 (FRA 2005) (FAO, 2011d). This biomass data has been extrapolated with a linear inter-relationship to country level on a reference area with a 0.5 grade (longitude/latitude) (IIASA, 2011). The report provides an estimation of the global forestry inventory for 1990, 2000 and 2005. It comprises reports from 229 countries and results developed in regional workshops (FAO, 2011d).

CGPM: The CGPM follows the approach developed by the FAO (between 1978 and 1981) using agro-ecological zones and is based on the world soil map of the FAO (1991). It considers in particular, three energy crops; sugarcane, corn and wood. Input data for this model include temperature, rainfall, soil data, carbon dioxide concentrations, plant specific growth parameters and yields. Furthermore, the model results serve as the data source for other models like IMAGE or the LCM2000 (PBL, NEAA, 2011b).

GLUE: This Model developed by Yamamoto, Junichi and Kenji (2001), considers land use competition and overall biomass flow. The model is based on data from FAO 1992, World Bank 1993, Intergovernmental Panel on Climate Change (IPCC) 1990/1992 and also data collected from the literature (Yamamoto, Junichi and Kenji, 2001).

GAPP: The Model developed by the University of Hohenheim, calculates the area potential. Several structural parameters, e.g. areas under cultivation, animal livestock, yields, population and per-capita consumption, are considered (BMVBS, 2010).

2.3.3 Results of the studies

Figure 5 presents the overall results categorised by time period and region as a logarithmic interpolation. The range of all study results lies between 242 PJ/yr (WEC) and 337 000 PJ/yr (SMEETS) for the entire period under review. The results for the African continent up to 2020 vary between 242 PJ/yr (WEC) and 6 679 PJ/yr (BMVBS). Looking long-term (2050 to 2100) the technical potential is expected to lie between 2 360 PJ/yr (HAKALA) and 337 000 PJ/yr (SMEETS). A detailed presentation of results according to different biomass categories – area potential and energy crops, forestry biomass, and residues and waste – can be found in the following sections.

Area potential and energy crops

The area available for the biomass production is a crucial parameter to calculate the quantity of raw material and total energy crop potential. Figure 6 summarizes the values of areas potentials calculated by five of the reviewed studies. According to these five studies, SSA has an area potential of at least 17.6 million ha, with Africa reaching a maximum area potential of 150 million ha. In the long term (2050), an area potential up to 717 million ha is assumed.

Over the short- and mid-term time period (2015-2020) the area potential calculated by BATIDZIRAI provides the highest values found in any paper, albeit only for Mozambique. Other high values found include those from KALTSCHMITT (Figure 6). For the time period leading to 2020, BMVBS forecasts the largest range of values for a number of different scenarios (1.56 million ha to 20.6 million ha).

According to Figure 7, the studies that show a high area potential over a specific time also have the highest amounts of energy crop potential (see KALTSCHMITT, BATIDZIRAI and SMEETS). However, in general, the energy crops potential, for the period up to 2020, ranges from 0 PJ/yr (HAKALA) to 13 900 PJ/yr (KALTSCHMITT). The high energy crop potential value for Africa of 13 900 PJ/yr determined by KALTSCHMITT, is in sharp contrast to the average value for Africa of 992 PJ/yr, from studies for the same time period. More values are found from studies for the year 2050, with a low energy crops potential of 0 PJ/yr calculated by HAKALA and BMVBS, which is in contrast to the value of 317 000 PJ/yr produced by SMEETS. Finally, two of the evaluated studies provide figures for the year 2100. While in YAMAMOTO no energy crop potential is expected in 2100, HOOGWIJK assumes a potential between 74 000 PJ/yr and 279 000 PJ/yr.

Forestry biomass

Five studies present results for the category “forestry biomass” (Table 3). The authors use the term fuel wood potential with the exception of FISCHER who refers to the data with the expression ‘forestry products’; a term, which is not clearly defined. An overview on the results of the forestry potential is shown in Figure 8.

A direct comparison of results is not possible, because of variations between the studies. The studies of DASAPPA, FISCHER and YAMAMOTO all refer to SSA, but relate to different time periods. They present a potential for SSA increasing from 0 PJ/yr for the present-day time to 75 000 PJ/yr for the year 2100.

Two of the studies (FISCHER and BMVBS) represent several scenario values for different time periods. The BMVBS report specifies three scenarios for 2020 and quantifies fuel wood potential between 949 PJ/yr and 2 459 PJ/yr, although these values refer only to four African countries (South Africa, Nigeria, Democratic Republic of Congo and Ethiopia).

The fuel wood potential of Nigeria by 2020 is predicted to be 0 PJ/yr, whereas South Africa (242 PJ/yr to 1 200 PJ/yr) and the Democratic Republic Congo (558 PJ/yr to 1 123 PJ/yr) provide the highest percentage of the overall values. The results for different scenarios presented by FISCHER range from 14 820 PJ/yr to 18 810 PJ/yr. Whereas, KALTSCHMITT indicates a current forest biomass potential of 5 400 PJ/yr for the whole African continent.

Residues and waste

Nearly all studies used in this report present data for waste and residual potentials; an overview is shown in Figure 9. In comparison to the wide range of results in the previous fields of energy crops and forestry biomass, the values for waste and residues show only moderate variation lying between 2 100 PJ/yr and 5 200 PJ/yr. The mean value from the studies of KALTSCHMITT, HAKALA, BMVBS, COOPER, HABERL and FISCHER is calculated as 2 900 PJ/yr. Even accounting for the different time periods, the deviation from the calculated average value is small.

Exceptional low values for waste and residual potentials can be found in the studies covering larger areas (WEC, 242 PJ/yr and DASAPPA, 585 PJ/yr), as well as in the country-specific studies for Ghana (DUKU, 0.1 PJ/yr, data not presented in Figure 9) and Mozambique (BATIDZIRAI, 10 PJ/yr). Comparatively high figures for the year 2050 are

found by SMEETS (12 000 PJ/yr to 20 000 PJ/yr) and for 2100 by YAMAMOTO (25 000 PJ/yr).

The reviewed studies consider different biomass categories in their analysis. In Table 5, the results for each biomass category are presented. The crop residues fraction has been analysed in the majority of studies in this report; in total 10 studies present results including this agricultural by-product.

Comparing these studies in Figure 9, it can be noted that HAKALA (2 380 PJ/yr to 2 600 PJ/yr), BMVBS (1 161 PJ/yr) and COOPER (1 089 PJ/yr to 3 588 PJ/yr) report similar results for the African continent for the current time period. Yet in contrast to these findings, DASAPPA states a comparatively low yield of only 135 PJ/yr for the SSA countries. In the longer-term (2050) HAKALA expects a potential similar, if slightly lower than that found today.

Significant differences occur in a detailed comparison of crop residue data from the SSA. The results range from between 2 190 PJ/yr (HABERL) and 20 000 PJ/yr (SMEETS). A crop residue potential of approximately 10 500 PJ/yr, which is comparatively high for the year 2100, is calculated by YAMAMOTO.

A large range in results also occurs for animal residues. COOPER (1 450 PJ/yr) and KALTSCHMITT (1 200 PJ/yr) present similar findings; with the BMVBS study indicating a low yield of 28 PJ/yr for the same region and time period. Significant differences are also shown for industrial wood waste (0 PJ/yr to 356 PJ/yr) and for logging residues (0 PJ/yr to 822 PJ/yr). The estimated potential for bagasse (201 PJ/yr to 242 PJ/yr) and coconut shells (11 PJ/yr to 15 PJ/yr) are almost identical in the two studies that included them.

Table 5: Residue and waste biomass potential energy data for Africa (PJ/yr.)

Study	Crop residues	Animal residues	Municipal waste	Industrial wood waste	Logging residues	Bagasse	Coconut shells	Oil palm
KALTSCHMITT	900	1 200	-	-	-	-	-	-
HAKALA	2 380-2 600 (current) 2 360-2 370 (2050)	-	-	-	-	-	-	-
BMVBS	1 161	28	353	4	822	208	11	88
COOPER	1 089-3 588	1 450	-	-	-	86-201	15	-
WEC		-	-	-	-	242	-	-
DASAPPA	135	-	-	356	94	-	0.001	0.007
DUKU	0.07	-	-	-	-	-	-	-
BATIDZIRAI				2	1	8	-	-
HABERL	2 190	-	-	-	-	-	-	-
FISCHER	4 884	-	-	-	-	-	-	-
SMEETS	12 000-20 000	-	-	0	0	-	-	-
YAMAMOTO	42 % (10 500)	not specified	-	not specified	not specified	-	-	-

Figure 5: Total technical biomass potential for different African regions and time periods

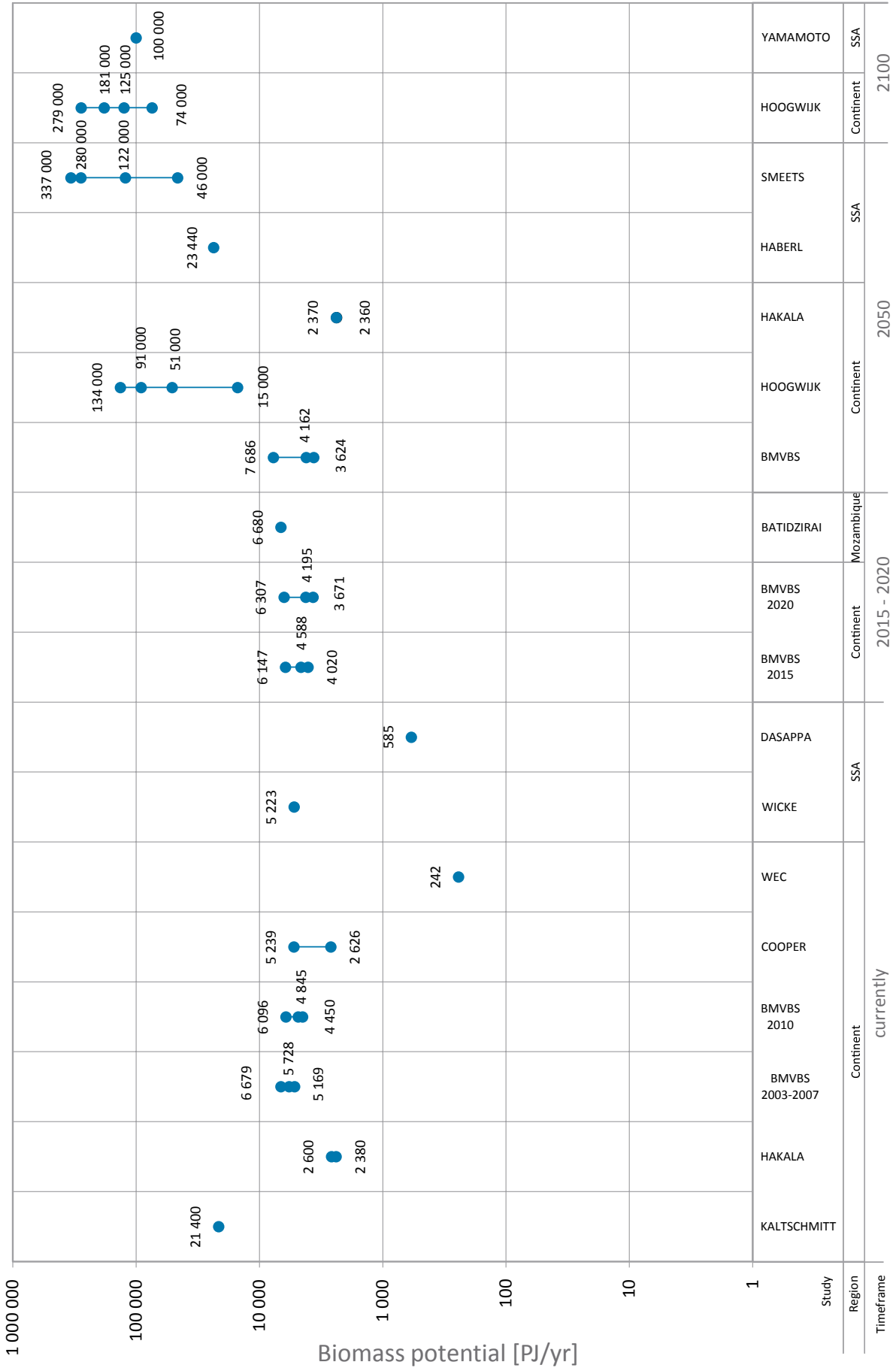


Figure 6: Area potential as dependent on time-period, African region and study

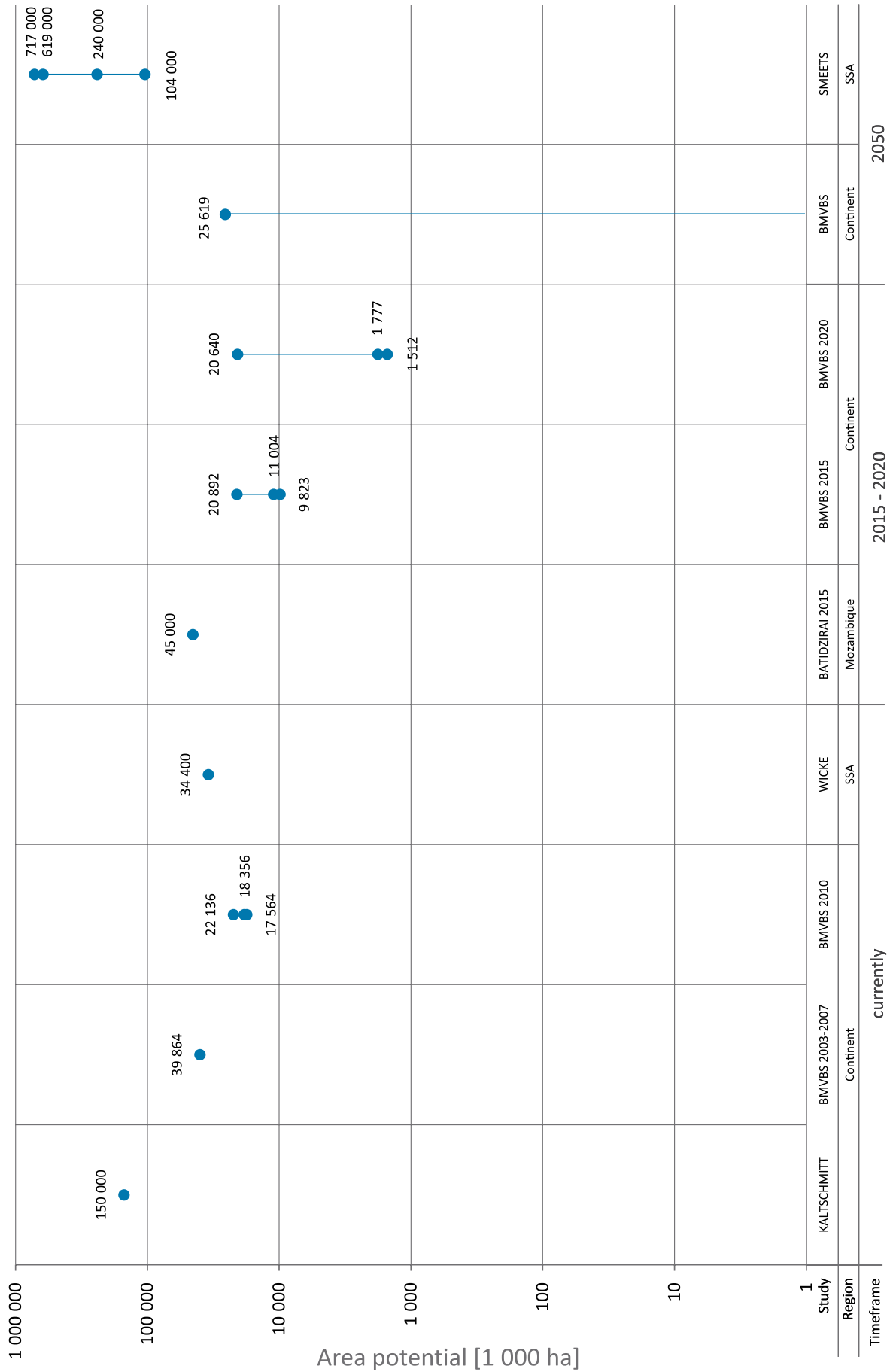


Figure 7: Energy crops potential as dependent on time-period, African region and study

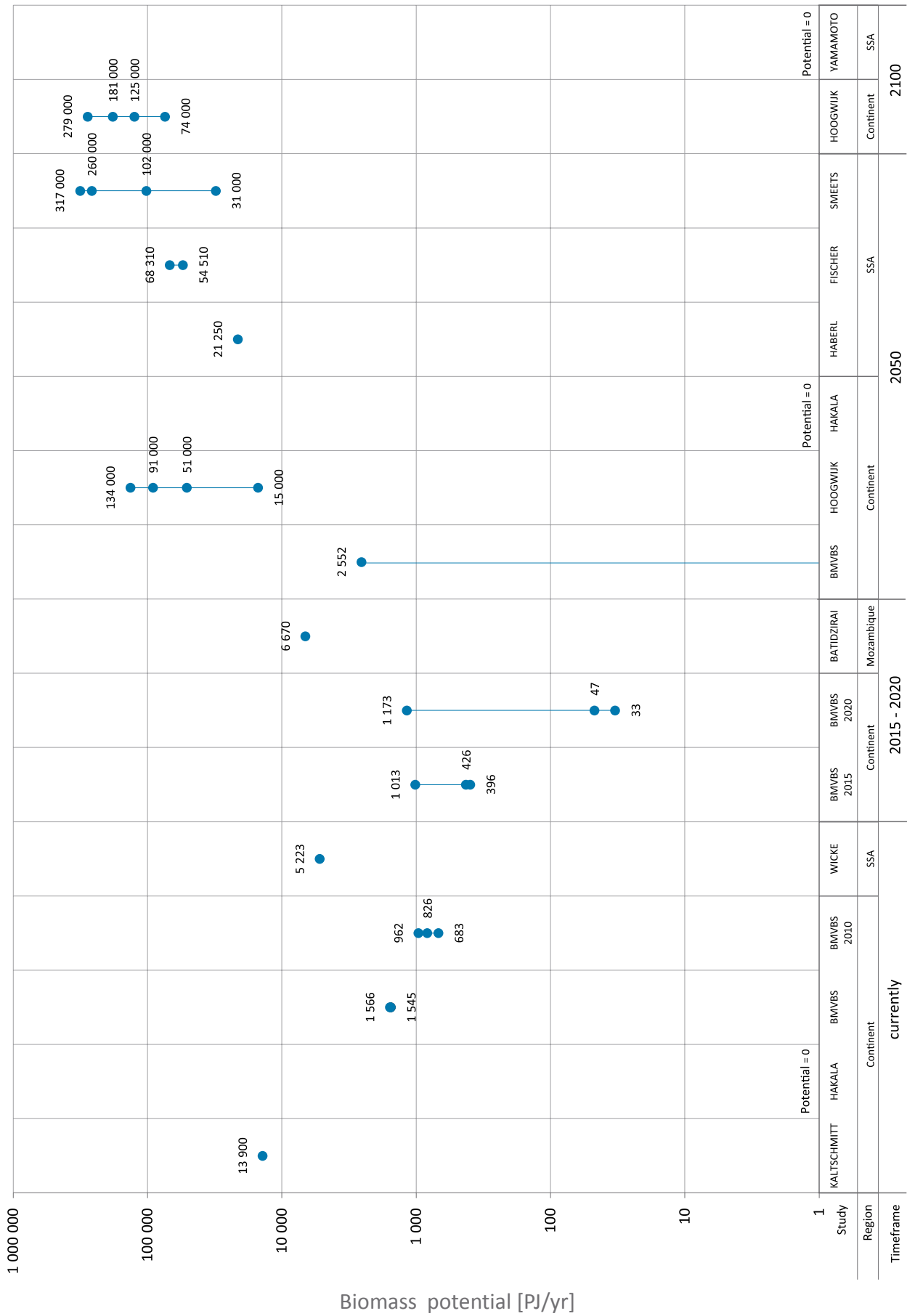


Figure 8: Forestry biomass potential as dependent on time-period, African region and study

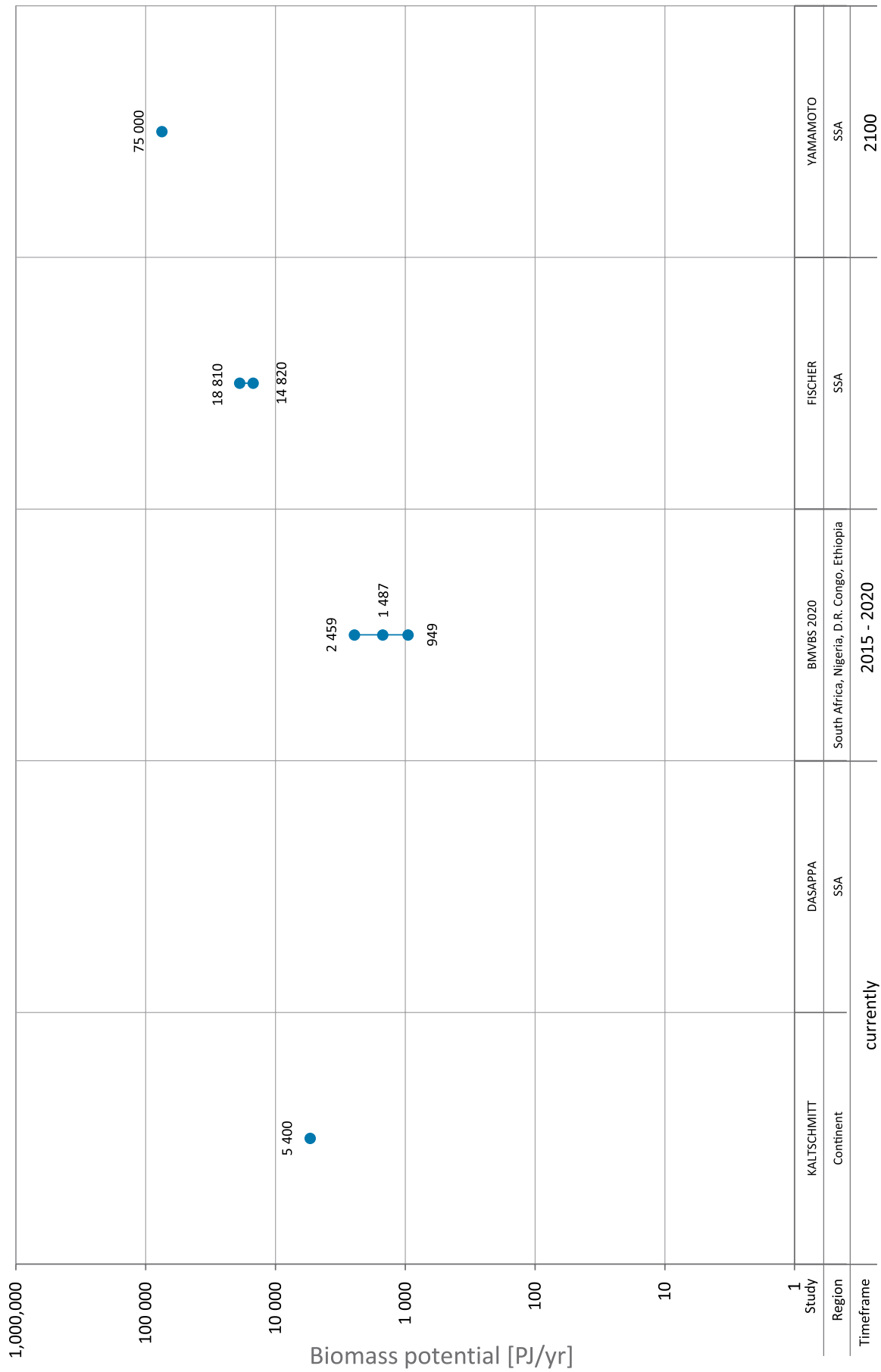
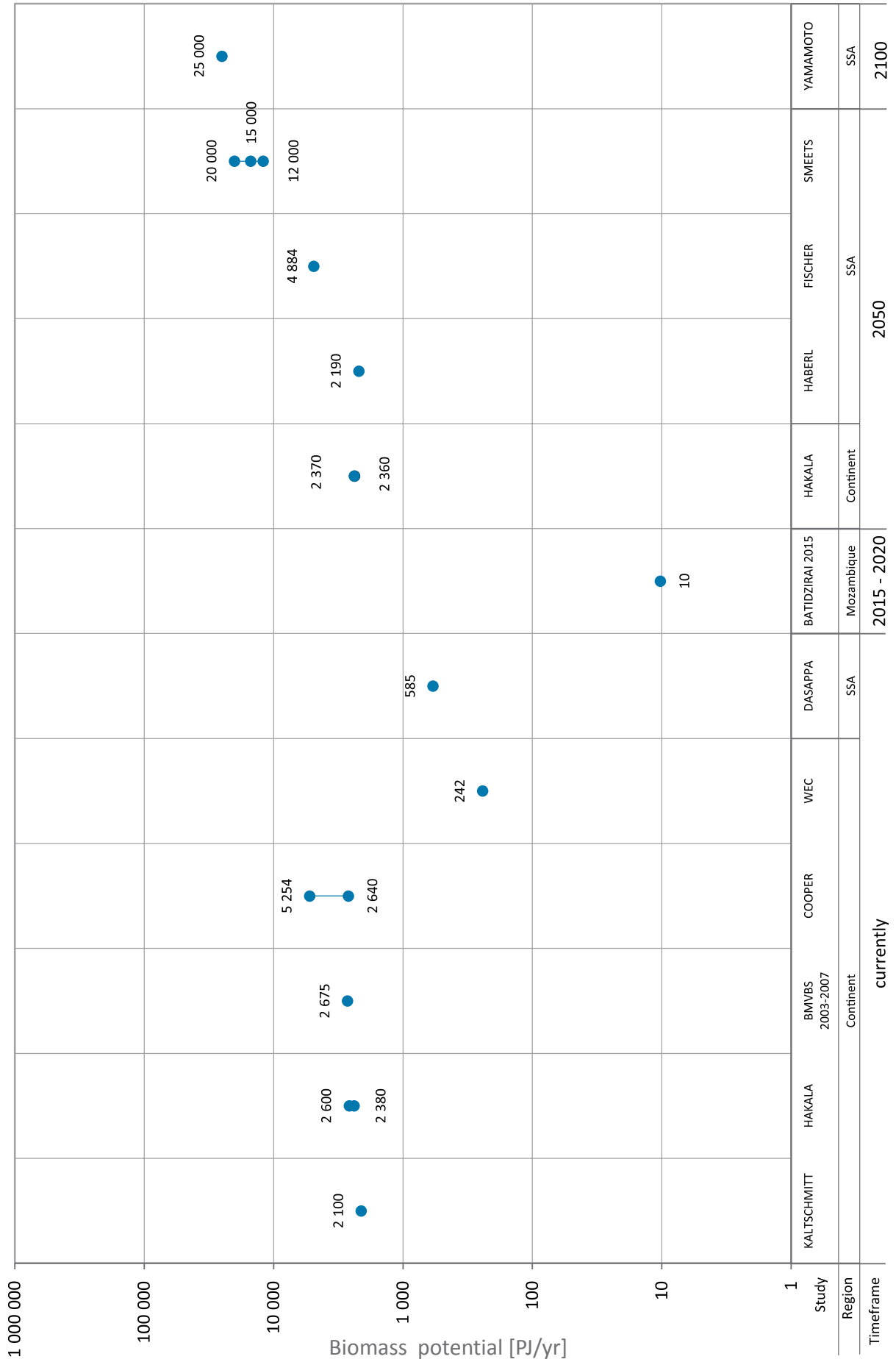


Figure 9: Residues and waste potential as dependent on time-period, African region and study



2.4 DISCUSSION

The potentials calculated by the reviewed studies refer to different time periods, geographical regions and biomass fractions. The studies therefore require careful consideration before comparing their results. The comparisons are hampered by a different definition for the technical potentials (see Section 2.3.1). Ultimately only a few parameters are incorporated into the calculations. This report finds major differences between the reviewed studies, applied methodology, underlying databases and the assumptions made.

In the following, the results for the area potential, energy crops, forestry biomass and residues and waste are discussed. Significant differences are expounded.

2.4.1 Area potential

The area potential is found to be a critical variable in determining the quantity of raw material. Most of the studies evaluated fail to mention the calculated area potential. The results of the remaining studies demonstrate that large area potentials can lead to high potentials of energy crops. The availability of land and the production yield of the energy crop are inherently uncertain parameters and both tend to be estimated differently (Berndes, Hoogwijk and Broek, 2003). For assessing the future area potential, the studies estimated the available land, which depends on population growth, eating habits, increased urbanisation, and so on. In theory an increase in yield could lead to a release of land for energy crop cultivation.

Of all the studies reviewed, only the BMVBS study shows the development of the area potential for different time periods. In two scenarios, a reduction in the area potential is predicted. The area potential is assumed to range from between 1.5 million ha and 1.7 million ha by 2020, and 0 million ha in 2050. These calculations are greatly affected by the increased demand for food. An increased potential may only be realised (25.6 million ha in 2050) if biomass energy use is to be supported, for example, by government policies that may incentivise farmers to cultivate the most efficient crops (e.g. Short Rotation Coppice (SRC), corn silage). Policies are not explored further in this report. The assessment of the current area potential by BMVBS assumes that land set aside from food production can be used and that additional land will be available if agricultural overproduction is used for bioenergy production.

All other studies indicate the area potential for a given year, without depicting the development of this potential. From the literature examined, by far the highest area potential was determined by KALTSCHMITT (150 million ha). Generally the authors assumed that 10% of agricultural area could be available for energy crop cultivation in the world. In contrast, a more explicit determination of area potentials was conducted by WICKE with a GIS-approach. The available land (34.4 million ha) for energy crop production resulted from the difference between the total area and the non-usable area. The latter included unsuitable areas (e.g. cities, sandy desert and dunes), high biodiversity areas and agricultural land.

The future area potentials assessment is carried out in only three of the studies reviewed. In BATIDZIRAI, the calculated area potential for Mozambique (45 million ha) is high mainly due to the increased efficiency in food production. Despite the increasing demand for food, more area is made available through efficient crop production. It must be noted that this potential can only be achieved if in 2015 the average crop yields increases by more than four times (from 4.9 to 8.9) and the average feed conversion ratio more than doubles (from 1.3 to 4.5). The resulting yields and the feed conversion efficiency in Mozambique would then be equivalent to an industrialised country's highly efficient production system.

Similar to the assumptions used in BATIDZIRAI, SMEETS calculates an area potential of 717 million ha for SSA in 2050 that is dependent on the agricultural production system. The precondition is also very high levels of technology for crop production and feed conversion efficiencies in Africa; this includes an increased use of fertilisers and agrochemicals. To date, globally, SSA has one of the lowest fertiliser usages in the world (Hakala and Pahkala, 2009). Another point raised is that food cultivation is projected onto areas that achieved the highest yields per hectare for a particular crop. Only through keeping food cultivation areas to a minimum and optimising production will there be more area available for energy crop production.

Due to the small number of studies available, it is difficult to make any general statements about the major causes of the significant difference found between the area potentials. Although it is possible to determine the area potential, using a general calculation (x% of total agricultural area), which is the simplest approach compared to those found in the studies; however, the assessment of future area potentials depends largely on the underlying assumptions. According to the results analysed in this report, the high

area potentials required for Africa can only be realised if efficient production systems are assumed, or if a focus is made on biomass use for energy production (e.g. increasing support). In summary, only by transforming the current inefficient and low-intensive agricultural management systems into state of the art production systems using the appropriate technologies can the area potential illustrated in most of these studies be achieved.

2.4.2 Energy crops

The most dominant parameters used to determine the potential of energy crops are land and yield. All results are considered with regard to, timeframe; geographical coverage; the type of potential; and the biomass feedstock (see Section 2.3.1). There are fundamental differences between the calculated potential amounts in the reviewed studies.

For the period up to 2020, the amount of energy crop potential shows range between 13 900 PJ/yr (KALTSCHMITT) and 0 PJ/yr (HAKALA). HAKALA justified this value by reasoning that Africa will continue to have food production problems for a significantly growing population in the future. According to the authors, a deficit in food production also indicates there is no land available for energy crop production.

When interpreting the results, for example, KALTSCHMITT used a general estimation that the potential area for energy crop cultivation was equivalent to 10% of the total agricultural area. Compared to other studies, this simple assumption leads to the largest potential of energy crops found in any study. Whereas, the calculated value for Mozambique in BATIDZIRAI (6 670 PJ/yr) can only be achieved if there is to be a large increase in food production efficiency that corresponds to a level found in industrialised countries (see Section 2.4.1).

The values presented in WICKE indicate area potentials that exclude other competitive land uses, such as land for hunting or livestock, due to the chosen methodology. Excluding these areas leads to a reduction in available land and a reduction of the calculated energy crop potential. A different picture emerged in the BMVBS study, in which the calculated values vary according to the chosen scenario. It should be noted that the highest values are only realised in the “bioenergy scenario”, which assumes an increasing focus on biomass use, e.g. through a cultivation of SRC or sugarcane. If previous trends regarding agricultural

development, land use change and population growth continue, or environmental and conservation restrictions increase, the calculations show that there can be a decrease in the energy crop potential (33 PJ/yr to 47 PJ/yr in 2020 and 0 PJ/yr in 2050).

The highest value of 317 000 PJ/yr for the energy crop potential is determined by SMEETS with the key parameter in this study being the efficiency of food production. However, only with very high crop production efficiency and through improved agricultural technology or geographical optimisation (see Section 2.3.3) can it be possible to realise this potential by 2025.

Six studies estimate the potential of energy crops in 2050; the average value found for Africa is 76 508 PJ/yr. Two of these studies (HAKALA, BMVBS) indicate that there is no potential for energy crops by 2050, mostly due to the high future population demand for food. In BMVBS an energy crop potential of 2 552 PJ/yr is only achieved with a scenario that has a focus on energy crop cultivation.

The values for 2050 determined by HABERL (21 250 PJ/yr) and FISCHER (54 510 PJ/yr to 68 310 PJ/yr) lie in the lower to middle range of the calculated values. The increase in biomass potential found by HABERL, are primarily explained by the assumption of a global increase of 54% in yields and also by a 9% expansion in cropland. Although improvements to the current productivity levels are implied in this study, there is no massive intensification of land management assumed.

A wide range of results for the year 2050 is shown in HOOGWIJK (15 000 PJ/yr to 134 000 PJ/yr). It is assumed that abandoned agricultural land, low productive land and ‘rest land’ (mainly savannah, scrub and grassland/steppe) are available for energy crop production. The area potential is determined with the model IMAGE (see Section 2.3.2). An area reduction is achieved by the so-called land-claim exclusion factor. This factor indicates the percentage of land that is not available for biomass production, e.g. claims for nature development, urbanisation, or cattle grazing on extensive grassland. The authors note that this factor for the competing land-use claims is associated with a high degree of inaccuracy. The selection of the land-claim exclusion factors for ‘rest land’ area is arbitrary, but has an important influence on the total estimated potential. It should also be stated that on a global scale the potential are assumed to be available for energy crops corresponds to 30%-40% of the total land area.

Only two studies assess the potential for 2100. HOOGWIJK, calculates a potential for energy crops ranging from 74 000 PJ/yr to 279 000 PJ/yr, depending on the scenario⁷, as opposed to YAMAMOTO who assumes that there is absolutely no potential from energy crops in 2100. In the latter study, this result is explained by a high demand for land due to the rising per capita consumption of meat and despite an increasing availability of land (through the use of fallow and degraded land) and increasing productivity in developing countries. This demand for meat counteracted the growth in area, so that finally no areas are available for energy crop cultivation. In YAMAMOTO, these material flows are simulated using the model GLUE (see Section 2.3.2).

2.4.3 Forestry biomass

Only five of the reviewed studies provide values for forestry biomass potentials. The results present a very wide range from 0 PJ/yr to 75 000 PJ/yr (see Section 2.3.3). A direct comparison of the published results is impractical, because the findings are based on different regions and time periods. Yet it is possible to discuss the applied methodology and the assumed framework conditions.

For the African continent today, KALTSCHMITT derives a potential of 5 400 PJ/yr using a calculation based on FAO numbers for raw wood harvesting. The theoretical increments of timber account for approximately half of the calculated potential.

DASAPPA, FISCHER and YAMAMOTO provide information on the SSA region. Although these studies partly use the same data set, the results are very divergent (Figure 8). DASAPPA calculates a potential of 0 PJ/yr for the current time, using a figure of 600 million people living in the region without access to energy; a per capita consumption of 0.89 m³/yr of fuelwood is calculated for cooking and heating that leaves no wood resources for other energy requirements. FISCHER calculates that forestry production potentials range from 14 820 PJ/yr to 18 810 PJ/yr for the year 2050. In this study the evaluation data for yield and availability are collected from the literature up to the year 1992 and then combined with FAO land use data from 1999.

This data is computed with the IIASA-model. YAMAMOTO uses their self-developed model GLUE to predict biomass potentials up to the year 2100. The calculated forestry production potential for SSA reaches 75 000 PJ/yr (Figure

8). This calculation is based on the average development from 1961 to 1990 and then uses a linear projection annually to 2010. Their basic assumptions include afforestation and future biomass demand. For developing countries YAMAMOTO assumes a perfect reforestation until the year 2025 and a constant biomass demand based on the 1990s level.

The BMVBS calculations of 949 PJ/yr to 2 459 PJ/yr biomass potential, use the country's average annual change to forest and plantation areas since 1990, which in combination with a country's specific annual net increase, can be used to derive the sustainable extractable raw wood potential. The calculations link a time series of production and consumption figures, as well as the gross domestic product and population data. The main data sources are the FAO databases. The potentials are calculated for three scenarios with varying framework conditions.

The highest potential can only be achieved through the ambitious implementation of forest plantations. The lowest potentials can be obtained in a scenario where 50% of the primary forest in the tropics and 10% of commercial forest in the temperate zones are put under protection.

In this global approach it is impossible to account for all relevant factors influencing the raw wood potential for every country and as such the findings of the BMVBS study rely on partial rough estimates and assumptions. Considering the inconsistent forest types and tree stands worldwide, net increases can also only be estimated. Possible developments of infrastructure and technology are not taken into account.

The studies analysed have a number of points concerning the data quality, e.g. production and consumption parameters, as well as the lack of data for the estimation of the forest biomass potential. Despite the fact that almost all the studies are based on FAO data, the results differ greatly.

⁷ The four scenarios used in the study correspond to the scenarios published by the IPCC.

This is explained through the use of different timelines, as well as further data processing using other datasets or models. In addition, the calculated potentials are influenced by the assumptions concerning several determinants, e.g. the factors for reforestation and biomass demand set by YAMAMOTO are simplified and do not capture the whole picture. Another critical factor is the data itself, which being generated in the 1990s, is considered from today's perspective flawed, i.e. the productivity yield calculation.

Additionally the lack of official statistics and the material use of timber are not considered sufficiently in the models used. The dynamic demographic development, especially in the very poor regions of Africa, is assumed to cause an increasing demand for fuelwood for cooking and heating. Furthermore a rising share of material use and export of timber can be assumed.

In light of this discussion, the forest biomass potentials can only be considered as rough estimates for the assessment of the respective regions. Regional analyses based on current data are a precondition to allow sustainable use of forest resources for energy production.

2.4.4 Residues and waste

In the analysed studies, different residual fractions (Table 3) are considered. Although the overall results are mostly similar, the individual results are compared (Table 5).

Most studies have findings for crop residues. For the current investigated period HAKALA (2 380 PJ/yr to 2 600 PJ/yr), BMVBS (1 161 PJ/yr) and COOPER (1 089 PJ/yr to 3 588 PJ/yr) provide broadly similar values for the entire continent. In all three studies the potentials are determined by using crop yield factors, such as soil quality, crop heating value, crop straw ratios and the corresponding crop residue fractions. For this purpose HAKALA uses literature data and their own calculations. The BMVBS calculations are based on a region-and crop-specific grain-to-straw ratio. Whereas, COOPER uses factors that are based on literature data for Asia.

To protect the soil quality only a small part of the total potential should be used for energy generation. This part depends on diverse factors (e.g. crop rotation, fertiliser use) and is estimated in the studies by a (sustainable) recovery rate. HAKALA estimates this rate to be 50% to 70% while the BMVBS study uses conservative 20% and COOPER uses 35%.

With the help of specific heating values, the remaining residue potential is converted into units of energy. HAKALA and COOPER use a uniform number of 18 GJ/t, for all crops. BMVBS calculations utilise a slightly lower value of 17 GJ/t. KALTSCHMITT evaluates a crop residue potential of 900 PJ/yr, but gives no explanation on how this is reached. Nevertheless, this value is still of the same order of magnitude as those described in the other studies.

Despite a similar methodological approach, the respective residue and waste energy potential results calculated for the Sub-Saharan region differ considerably. DASAPPA calculates a very low 135 PJ/yr for the present-day. For the year 2050, the results range from 2 190 PJ/yr (HABERL) to 20 000 PJ/yr (SMEETS). The amount of crop residue can be estimated from the assumptions made for area, energy crops potential and yield development (Section 2.4.2). High energy crop potentials are linked to high crop residue potentials. In particular, the high yield expectations found by SMEETS leads to high values for the estimated crop residues. This relationship is also evident in FISCHER. YAMAMOTO indicates no specific value for crop residues for the year 2100, but estimated a proportion of 42%. As this value is not mentioned in a global context it is taken to only be conditionally related to Africa.

The quantity of crop residue is determined by the parameters such as area, and crop productivity, including the amount of raw material and the different recovery rates for the crops produced. The results for Africa at present vary only slightly. The differences arise from the factors used to determine the fraction of residue, the (sustainable) recovery rates, and the varying sample site conditions. Taking into consideration the methodology and the relatively small deviations in the results, the potential of crop residues would range between 1 000 PJ/yr and 3 000 PJ/yr. Further analyses with actual and updated regional databases are necessary to specify and corroborate these figures, given the importance attached to yield and its role in future potential energy evaluations.

In three studies the potentials of animal residues are presented for the whole continent. The values of KALTSCHMITT (1 200 PJ/yr) and COOPER (1 450 PJ/yr) are very similar. In contrast, the potentials calculated by BMVBS are very low (28 PJ/yr). The calculations are based on FAO animal data and subsequently multiplied by specific energy content. COOPER's calculations assume 223 million cattle, and each animal is assumed to produce 50 gallons (gal) of animal residue, with an



Wooden pellets©Jiri Hera/Shutterstock



energy content of 130 MJ/gal. However, the authors stress that the results refers to the traditional use of dried excrement and draws attention to one the biggest challenges facing Africa, which is the ability to create an appropriate infrastructure for large-scale excrement use. KALTSCHMITT also assumes an energy-related use of a dried solid fuel.

The calculations include an additional factor of 50% for the development of excrement amounts of cattle and pigs. In the BMVBS calculations, the FAO average values used are from 2003-2007 (237 million cattle, 21.6 million pigs, 1.2 billion chickens). All countries investigated by the studies are characterised by a poor infrastructure. Therefore, additional country-specific factors of the future development of excreta use are applied. These factors are assumed to be at a very low level for animal residue potential: for pigs between 15 to 30% and for chickens 30 to 70%. For beef a development factor of 0% is expected and could explain the significant difference in the results of COOPER and KALTSCHMITT.

The demand for milk and meat is expected to increase in the future with an increasing population. The production of animal residues is expected to increase. The FAO livestock data are not sufficiently detailed to make an estimate, since the individual stocks (e.g. beef cattle, dairy cows and calves) are not separately listed. Animal species difference will also have a significant impact on the amount of the

excrements and the possible associated energy yields. Results using the FAO database must be interpreted with caution. Moving forward, the improved capture of animal residue potential in Africa lies in the development of an appropriate infrastructure.

Only the BMVBS study calculates the municipal waste potential; 353 PJ/yr. To determine this potential, the FAO population data and IPCC information on the per capita biomass resources in year 2000 are used. The technical fuel potential is then calculated with a development factor of 75%. If the population rises, the volume of municipal waste will increase, especially in major cities. Inaccuracies in the data arise from the information about theoretical potentials per capita and other differences in the regional development factors.

Data for industrial wood waste potential ranges from 0 PJ/yr (SMEETS) to 356 PJ/yr (DASAPPA). All authors describe the FAO database as limited, with fragmented data. BATIDZIRAI (2 PJ/yr) provide calculations for Mozambique based on forest area and identified industrial wood waste potential for sustainable logging. The analysis derives a potential with regard to the wood processing industry that takes into account an additional efficiency factor of 55%. BMVBS (4 PJ/yr) and SMEETS (0 PJ/yr) also use this factor, but assume 75%. DASAPPA assumes a relatively small factor of 30% for energy production (356 PJ/yr). However, in general the calculations reveal a high potential and



Panorama of Nairobi, Kenya ©John Wollwerth/Shutterstock

such numbers possibly result from the assumptions being made, the theoretical potential and the underlying wood yields being used. In the aforementioned studies, only the most essential factors are considered. In many cases, they are only partially taken into account. For example, different wood types cannot be distinguished. Also the material use can be estimated only very roughly. The results therefore provide very approximate values

Equally, the data concerning the logging residues is of poor quality. The BMVBS study calculates a potential of 822 PJ/yr. It is assumed that the logging residues constitute approximately 30% of the raw timber from felling; 50% of this material is available in form of a technical fuel potential. Other assumptions are also made with respect to the tree species composition, age, class, growth-rates and distribution.

The underlying raw timber production quantities are also ambiguous (Section 2.4.3). The reliability of the results is further reduced by additional assumptions. DASAPPA (94 PJ/yr) assumes that 10% of the total potential is available for energy-related use, whilst SMEETS calculates a potential of 0% for 2050. The scale of the results shows that despite a similar methodological approach, the assumptions used in the studies strongly influence the final results. Concurrently, it is not clear whether, or how the quantity of existing material was considered.

Very similar results are calculated by BMVBS (208 PJ/yr), COOPER (86 PJ/yr to 201 PJ/yr) and WEC (242 PJ/yr) for bagasse. All authors use the FAO production data to convert the energy content in existing biomass into specific energy potentials. The material use, however, is not considered by the studies and therefore the values represent the upper limit of the possible potential. The information concerning coconut shells and palm oil has to be interpreted with caution, as once again, only maximum values are calculated.

In summary, the underlying yield data for both energy crops and forestry biomass have a decisive influence on the agricultural and forest residue potential. For the current crop residue potentials, three studies confirm a range from 1 000 PJ/yr to 3 000 PJ/yr. The results show a similar potential for the animal residues when the use of dried excrements is considered. To date, however, the lack of infrastructure impedes the industrial-scale use of the animal residue potential.

Similar values for bagasse and coconut shells are calculated. Large uncertainties appear in the results for the wood and crop residues for the future potentials. The volume of waste residues will increase with a rising population. To what extent energy-related use is possible depends on both the waste material available for use and the available infrastructure to capitalize on this form of energy.

2.5 CONCLUSION

The aim of this study was to provide an update on biomass potential for energy use in Africa. For this purpose, 14 publications published after the year 2000 that include results for the African continent, its regions or its individual countries, were evaluated. The comparison included a detailed analysis of the time and geographical extent, the definitions used to describe the calculated potentials, the considered biomass fractions, the major databases and other dimensioning factors. Subsequently, the analysed publication results have been merged, sorted into different categories (area potential, energy crops, forestry biomass, residues and waste) and the findings were discussed.

Only a few of the investigated publications specify the area potential that is used to calculate the overall biomass potential from energy crops. Therefore, it is not possible to make generalising statements about area potentials for bioenergy production in African countries. The highest area potential amongst the evaluated publications is based on a rather general estimation of available land (see KALTSCHMITT). All other publications show an overall average area potential of 19.6 million ha. The estimation of future potentials is also driven by assumptions on the development of agricultural production systems. The high values of area potentials for the long term shown in some of the publications (see SMEETS and BATIDZIRAI) are only achievable if African countries can increase their agricultural productivity to the level of that found in developed countries.

The potential of energy crops calculated in the studied publications is mainly determined by the area potentials and crop yields. The assumptions used in calculating area potential, as well as other land categories e.g. land for hunting, grazing land or savannah, differed greatly between the publications. In addition, assumptions for areas of exclusion that are thought not suitable for agricultural purposes are highly ambiguous and often given as a rough guess by the authors. Accordingly, the calculated potential of energy crops in Africa range between 0 PJ/yr and 13 900 PJ/yr. Future energy crops potentials are predicted to average between 76 508 PJ/yr for 2050 (six studies) and 131 800 PJ/yr (two studies). Lower estimates for future energy crops potentials are justified through an assumed increase in food demand -which is also driven by an increasing consumption of meat- due to population growth; leaving little or no area available for the energy crop production. It is noted that the higher estimates of future energy crop potentials in Africa, are only feasible

under the assumption that production efficiency will increase and/or by narrowing the focus of energy crop cultivation (so-called energy crop rotations).

Five of the evaluated publications include results for African forestry biomass potentials. However, the results are neither regionally nor temporally comparable. There is a wide range in the results, with 0 PJ/yr estimated for our current time period, to 75 000 PJ/yr for the year 2100. The most important parameters used are the forest surfaces, yield expectations, the raw wood production and the material use. The databases, mostly compiled by FAO, are incomplete and lack details (e.g. forest types, tree existence, conservation status). Additionally, the databases are partly obsolete. The land use can be substantially different today and therefore these databases need to be questioned in principle. With such large uncertainties the estimations can be a problem for material use, since there are no related statistics available. The economical potential of forestry biomass must therefore be interpreted with caution. A regional analysis and evaluation of forest resources would be necessary to provide better estimations in the future.

Twelve studies calculate the residue and waste potentials. Three studies confirm for the present-time a crop residues potential between 1 000 PJ/yr and 3 000 PJ/yr. A narrow range in values is also found for bagasse (201 PJ/yr to 242 PJ/yr) and coconut shells (11 PJ/yr to 5 PJ/yr). The results concerning animal residues potential are consistent (1 200 PJ/yr to 1 450 PJ/yr), if a traditional use is assumed. The results for wood waste are variable: 0 PJ/yr to 356 PJ/yr industrial wood waste; 0 PJ/yr to 82 PJ/yr logging residues. Numerous assumptions have to be made due to insufficient data, e.g. concerning share of raw material, which cannot be confirmed without additional statistical data. Equally uncertain are the long-term forecasts for crop residues (2 190 PJ/yr to 20 000 PJ/yr).

The main reasons are the underlying land and yield assumptions. The amount of the residual material is inter alia influenced by the demographic development. In principle, it can be assumed that the crop residue amount increases, but the proportion of material and its use is uncertain, leaving it open for interpretation. Large scale energy-related use of residues and waste potentials often fail due to the lack of the infrastructure. The development of biomass potential is largely dependent on a concept of cost-effective logistics. The necessary costs are (under consideration of the current fossil energy prices) often too high.



However, through the regional analysis a cost-effective use may be verified and best-practice examples can be implemented. Further investigations are necessary with respect to this.

The poor data availability constitutes the main problem. The land availability is a limiting factor for the biomass production. In this regard WICKE criticised the poor basis of the data concerning the current land use and emphasises that many land uses (e.g. in culturally rich regions, areas of conflict) are not considered in the calculations. Regions with a high biodiversity and special protection status are also insufficiently considered. The assumption about yields and calculations are also problematic. Often, only relatively inaccurate average values are determined. The yield data is taken partially from literature sources that determined the values for similar regions. The impact of climate change on potential yield is also insufficiently taken into consideration. Other factors must also be incorporated into the calculations concerning the sustainable biomass use. These include for example Greenhouse gas emissions from converted land, deterioration of soil quality/soil fertility, water requirements of energy crops and their impact on local/regional hydrological systems and the population. Social and socio-economic impacts of bioenergy, through displacement effects, must be considered in order to finally assess whether the energy-related use of biomass is a sustainable and climate-friendly option in the African energy sector (Wicke, *et al.*, 2011; Berndes, Hoogwijk and Broek, 2003).

The assessment of social criteria in energy-related use of biomass potential has been so far largely ignored. There is an urgent demand for research and action in this field. In particular, the land requirements and ownership situation must be analysed and long-term socially acceptable concepts of use have to be designed. The appropriate infrastructure is an important prerequisite for the development and utilisation of the biomass potential. Cost-effective use concepts depend on numerous local and regional factors, which have to be tested on site and be subsequently developed to become the best-practice examples.

The results to date on the African regional biomass potentials are only very approximate and are subject to great uncertainties. The potential calculations with outdated or inaccurate data can be inadequate; food security is a priority for the growing population and the rising per capita consumption needs to be also taken into consideration; The aim of future studies must be to identify, with the help of the correct and consistent methodologies, the priority areas where potential for the bioenergy production exists. Such effort was initiated by the Global Bioenergy Partnership, which developed 24 sustainability indicators. The GBEP indicators are intended to guide any analysis undertaken of bioenergy at the domestic level with a view to informing decision making and facilitating the sustainable development of bioenergy in a manner consistent with multilateral trade obligations.



Baobab trees, Madagascar©Pierre-Yves Babelon/Shutterstock

3. Summary



In this report, a total of 14 studies that attempt to determine biomass potential in Africa were analysed. The aim was to obtain reliable information about biomass potential in Africa and explain the significant differences between study results. Four categories were introduced to examine the studies: potential of area, energy crops, forestry biomass, and residues and waste.

Significant differences were detected in the geographical coverage and selected timeframes of the various studies. In most of the studies reviewed, biomass potentials are calculated on a global scale. The biomass potentials estimates for Africa refer either to the whole continent (including North Africa) or to Sub-Saharan Africa. A few other studies are based on a continental scale or directly focused on a particular African country. The most comprehensive information exists for the current situation and the year 2050. Future projections, short- and medium-term (2020 to 2030) as well as longer-term (2100), have been less frequently considered.

The analysed studies also differ widely in the types and quantities of biomass resource considered within a given biomass category, as well as in terms of overlaps between these categories. Finally, heterogeneous definitions of potential are used in the studies. Although all reviewed studies refer to technical potential, the underlying factors for assessing this type of potential, such as environmental or technical restrictions, vary considerably. The interpretation of the results should always consider the chosen timeframe, the geographic coverage, the biomass resources, and the definition of the potential used in the respective study.

Besides these heterogeneous terms and relationships, deviations in results also reflect important differences in the driving factors assumed for the future development of production conditions. Studies rely on different databases and different underlying assumptions associated with these factors. Biomass potential is highly dependent on the amount of available land and the level of production yields. An important driving factor in determining the potential of forestry biomass, along with available residues and waste, is the level of other

competing uses. The estimation of these parameters is generally associated with a high degree of uncertainty.

At this point, further research and development is necessary for biomass potential to be fully appreciated and developed. The assessment of biomass potential requires reliable, up-to-date data. According to the results available, the tremendous potential of energy crops can only be realised through an enormous increase in agricultural production efficiency. Therefore, the expansion and improvement of current agricultural production systems in Africa will play a crucial role in the sustainable development of modern bioenergy systems.

Due to the wide range in results, only the most limited, general statements can be made about current or future biomass potential in Africa at present. In most studies, the impacts of factors such as climate change and biodiversity on the amount of biomass potential have not been sufficiently analysed.

In the assessments of biomass potential conducted to date, the highest deviations in results have been observed for energy crops and forestry biomass, with the enormous heterogeneity reflecting an increased interest for analysing the potential of these types of biomass at a regional level. Greater compliance can be observed among the existing studies for residues and waste. The findings of this report for Africa are in line with the assessment carried by the IPCC (IPCC, 2011), which concludes that narrowing down the technical potential of the biomass resource to precise numbers is not possible. Reliable assessments can only be based on ground-based data collection and country-driven exercises.

Furthermore, sustainable use of biomass resources also requires the evaluation of environmental, social and economic criteria. These issues are addressed by the 24 sustainability indicators, developed by the Global Bioenergy Partnership.

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