Public Disclosure Authorized
Public Disclosure Authorized
Public Disclosure Authorized
Public Disclosure Authorized

THE WORLD BANK
IBRD • IDA | WORLD BANK GROUP

ESMAP
Energy Sector Management Assistance Program

Biomass Resource Mapping in Pakistan

SCOPING PHASE REPORT

October 2014

Photo credit: FAO

Food and Agriculture Organization of the United Nations

This report was prepared by the Food & Agricultural Organization of the United Nations (FAO), under contract to The World Bank.

It is one of several outputs from the biomass resource mapping component of the activity "Renewable Energy Resource Mapping and Geospatial Planning – Pakistan" [Project ID: P146140]. This activity is funded and supported by the Energy Sector Management Assistance Program (ESMAP), a multi-donor trust fund administered by The World Bank, under a global initiative on Renewable Energy Resource Mapping. Further details on the initiative can be obtained from the ESMAP website.

This document is an **interim output** from the above-mentioned project. Users are strongly advised to exercise caution when utilizing the information and data contained, as this has not been subject to full peer review. The final, validated, peer reviewed output from this project will be the Pakistan Biomass Atlas, which will be published once the project is completed.

Copyright@ 2014 Food and Agriculture Organization of the United Nations
Vialle delle Terme di Caracalla 00153 Rome, Italy

Copyright © 2014 International Bank for Reconstruction and Development / THE WORLD BANK
Washington DC 20433
Telephone: +1-202-473-1000
Internet: www.worldbank.org

This work is a product of the consultants listed, and not of World Bank staff. The findings, interpretations, and conclusions expressed in this work do not necessarily reflect the views of The World Bank, its Board of Executive Directors, or the governments they represent.

The World Bank does not guarantee the accuracy of the data included in this work and accept no responsibility for any consequence of their use. The boundaries, colors, denominations, and other information shown on any map in this work do not imply any judgment on the part of The World Bank concerning the legal status of any territory or the endorsement or acceptance of such boundaries.

The material in this work is subject to copyright. Because The World Bank encourages dissemination of its knowledge, this work may be reproduced, in whole or in part, for non-commercial purposes as long as full attribution to this work is given. Any queries on rights and licenses, including subsidiary rights, should be addressed to World Bank Publications, The World Bank Group, 1818 H Street NW, Washington, DC 20433, USA; fax: +1-202-522-2625; e-mail: pubrights@worldbank.org. Furthermore, the ESMAP Program Manager would appreciate receiving a copy of the publication that uses this publication for its source sent in care of the address above, or to esmap@worldbank.org.

Sustainable biomass production and biomass mapping for electricity in Pakistan (Scoping Phase)

Authors: Ana Kojakovic and Irini Maltsoglou

Rome, October 2014

EXECUTIVE SUMMARY

The Energy Sector Management Assistance Programme (ESMAP) of the World Bank has launched a new Renewable Energy Mapping Initiative. The initiative aims to map renewable energy resources for electricity generation and by this to inform the decision-making process of governments, private sector, and other stakeholders with respect to renewable energy planning and investments. The initiative covers four renewable energy options, i.e. biomass, small hydro, solar and wind. The mapping process has five phases starting from Phase 1 which covers detailed data scoping and preliminary mapping up to Phase 5 on development and agreement of a policy framework for investment support.

Biomass is a versatile resource originating from agriculture and from processing industries. This resource and can be converted into all final energy forms i.e. electricity, heat and liquid fuels. The assessment and mapping of the available biomass provides information on the amounts and location of the resources. This assessment can then be utilized for the identification of the viable technologies and best locations for the establishment of electricity generation facilities.

The Food and Agriculture Organization of the United (FAO) has been working on biomass production and bioenergy for several years on issues ranging from sustainable agriculture production to improvement in energy access and rural development opportunities. As part of its country support package, FAO developed the Bioenergy and Food Security (BEFS) Approach. The BEFS Approach supports countries in designing and implementing sustainable bioenergy policies and strategies. The BEFS Approach is structured around six areas of support, namely scoping, stakeholder dialogue and capacity building, sustainable bioenergy assessment, support to policy formulation, risk prevention, management and investment screening and impact monitoring and evaluation. The BEFS bioenergy assessment component is a core element of the BEFS Approach, supporting countries to generate country and context specific evidence to feed into their national policy process. Food security and sustainability requirements are built into the whole process, and more specifically into the assessment stage. The approach aims to find solutions that are food secure and sustainable and that target development and growth.

In order to ensure sustainable resource use and minimize negative socio-economic and environmental impacts potentially arising from bioenergy production, FAO integrates food security considerations and sustainability criteria in the assessment and mapping methodology. In accordance with FAO's Bioenergy and Food Security approach, biomass resources used for other purposes are not considered as readily available for bioenergy production. The proposed approach implies a quantification of the total amount of biomass generated annually and identification of the portion that is utilized for material and energy purposes, in order to calculate a net difference which represents the amount available for bioenergy production.

Pakistan has requested support from ESMAP to map the potential for electricity generation from renewable energy. FAO is collaborating with the World Bank for Phase 1 of the biomass mapping process in Pakistan. This report represents the baseline for the biomass mapping component in Pakistan and is the result of a comprehensive desk-based review of existing data and research. The report provides recommendations on the methodology and approach to be implemented in Pakistan for the biomass mapping component.

More specifically this report provides:

- An overview of the agriculture and energy context in Pakistan, especially in relation to potential biomass resource use
- Recommendations on suitable methodological approaches for biomass mapping and issues to be considered in the mapping process
- Review of available national and international data required for the biomass resource assessment and mapping process, and identification of data gaps
- Overview of relevant research and of related previous or existing activities
- Overview of the key institutions and organizations relevant for bioenergy sector.

Pakistan is the sixth most populous country in the world with a population of more than 182 million people in 2013 and two thirds of the population residing in rural areas. Income has been rising over the last ten years, reaching the level of 1,386 GDP/capita in 2013/14. The agriculture sector remains a key sector of the country's economy, contributing 21 percent of GDP in 2013/14 (Government of Pakistan, Ministry of Finance, 2014). In relative terms, undernourishment has been following a declining trend going from 19 percent between 2008 and 2010 to 17.2 percent in 2011-2013. Nonetheless, in absolute terms, the number of undernourished still remains high with 31 million people being reported as undernourished. Average per capita daily calorie intake was 2,428 kcal in 2011. Five food stuffs contribute 72 percent of total food calories, namely wheat (37%), milk (13%), sugar (10%), palm oil (7%) and rice (5%) (FAOSTAT, 2014a).

The energy sector in Pakistan has been facing substantial difficulties over the past decade. The main reasons for this have been high electricity generation costs, insufficient generation capacity and highly inefficient transmission and distribution systems (Government of Pakistan, 2013). This has resulted in an energy demand supply gap.

According to the International Energy Agency (IEA, 2014), the total primary energy supply in 2011 was 85,820 ktoe. The main sources for the primary energy supply were fossil fuels (61.4%), followed by traditional biomass (34.2%). Based on IEA statistics, the residential sector was reported to be the main consumer of energy, predominantly relying on traditional biomass to meet its demand, followed by the industry sector. The main energy sources for industry are reported to be natural gas (50 percent) and other fossil fuels and biomass. The Pakistan Energy Yearbook 2012 (Hydrocarbon Development Institute, 2013) does not include biomass and bioenergy when reporting on energy primary supply and consumption. Fossil fuels statistics appear to be in line with those reported by the IEA. Due to this different energy reporting system, based on the Energy Yearbook, the industry sector is reported to be the main consumer of energy followed by the transport sector and the residential sector. Thus, if biomass were to be available and the production of bioenergy economically feasible, this resource could play an important role in addressing part of the energy crisis problem in Pakistan.

The current levels of agricultural production in Pakistan indicate that there might be potential availability of crop residues, namely wheat straw, rice straw and cotton stalk, and of food processing residues, i.e. bagasse and rice husk. When assessing residue availability in Pakistan, it is important to consider that there are two cropping seasons, namely Karif and Rabi. This can mean that either a crop is sawn twice or that two different crops are harvested during the calendar year. This should be reflected in the mapping process. Primary and secondary crop residues can be converted into electricity through combustion, gasification and/or co-generation technologies. The selection of the most suitable conversion technology will depend on energy needs and the existing energy infrastructure required for transmission and distribution of electricity.

The commercial dairy sector has been growing in recent years in Pakistan, implying that there should be an increasing level of manure available. This could be used in the production of biogas. Anaerobic digestion of manure does not only contribute to energy supply, but represents a good manure management practice from an environmental point of view. The energy produced from biogas, be it heat and/or electricity, can be used for self-supply of dairy companies, off-grid rural electrification and/or supply into the grid.

In the case of wood harvesting and wood processing residues, it was not possible to draw any conclusions on the potential availability of residues from this stream. After reviewing the national, FAO and IEA statistics, it was observed that there are large discrepancies between reporting sources. For this reason, we recommend collection of data through interviews and field work and validation of the existing data, as part of the assessment and mapping exercise. That will allow a clearer understanding of the data reported and enable a correct presentation of the situation in the country.

The first step in bioenergy policy formulation in Pakistan was marked by the adoption of the "Medium Term Renewable and Alternative Energy Policy". This document was updated in 2013, with an emphasis on strengthening inter-ministerial dialogue in an effort to increase the efficiency of policy implementation. The Government also adopted a Framework for Power Cogeneration (Bagasse/Biomass) in 2013 to foster and mainstream the utilization of bagasse. However, there is still no overarching policy document defining the role of biomass as an energy feedstock, which would comprehensively address all aspects of biomass production and the implications on food security, livestock breeding and other economic activities that might arise. FAO's Bioenergy and Food Security Approach stresses the importance of inter-ministerial collaboration, through the creation of a multidisciplinary working group, that can define the country specific issues and priorities and technically assess or lead the assessment of viable bioenergy options . The governmental institutions should lead the policy development process, with the involvement of the private sector and civil society. The stakeholders relevant for the bioenergy policy dialogue at the federal and provincial level have been mapped and included in the annex of this report.

Table of Contents

List of Figures

List of Tables

1 INTRODUCTION

The Energy Sector Management Assistance Program (ESMAP), a multi-donor trust fund administered by the World Bank, has recently launched a new initiative to assist countries in mapping national renewable energy resources to inform the decision-making process of governments, private sector, and other stakeholders with respect to renewable energy planning and investments. Bioenergy is one of the renewable energy options being assessed. FAO has been working on biomass production and bioenergy for several years on issues ranging from sustainable agriculture production to improvement in energy access and rural development opportunities. More specifically, over recent years, FAO has focused its attention on supporting countries in developing a sustainable bioenergy sector while accounting for food security needs and constraints. FAO and ESMAP are now collaborating in the area of biomass mapping for electricity generation. This effort brings together FAO's expertise in this area, methodologies developed and technical experts for the application of biomass mapping for electricity generation within the ESMAP-led initiative.

The initiative covers five phases of renewable energy resource mapping and geospatial planning activities. The five phases follow the resource mapping process from data availability assessment, preliminary mapping and stakeholder engagement, to detailed geospatial planning, and to the development of policy recommendations. The initial phase, Phase 1, covers the scoping activities of data availability and assessment and stakeholder review.

Pakistan has expressed interest in receiving World Bank support for mapping the biomass energy potential of one or more provinces. It will be one of the first countries to carry out the biomass assessment for electricity production under the ESMAP initiative.

This report supports the very initial phase of the World Bank's work in Pakistan, i.e. Phase 1. More specifically the report outlines the baseline country information, data requirements and availability and recommendations on suitable methodological approaches for biomass mapping for electricity generation in Pakistan. The information provided is based on a comprehensive scoping exercise, a desk-based review of existing data and research, including supporting documentation for the biomass mapping activities in Pakistan.

The report is divided into six main sections. After the Introduction, the second section provides an overview of country baseline information including economic and poverty status, agriculture and food security indicators, definition of key food staples and key agriculture export crops and definition of the energy supply and demand profile of Pakistan. The third section presents the definitions of bioenergy and proposed approach and methodology for biomass resource assessment and mapping. The assessment methodology for each biomass type is explained in detail: crop residues, livestock residues, forest harvesting residues, wood processing residues and municipal solid waste. Data requirements for the assessment and possible data sources are also explained. This section also includes a short description of technologies used for electricity generation from biomass. Recommendations on the approach and scope of biomass mapping in Pakistan and an overview of data availability and data gaps are included in section four. Section five is devoted to bioenergy policy development. It presents the FAO's Bioenergy and Food Security approach on bioenergy policy development process and gives an overview of the relevant stakeholders for bioenergy policy development in Pakistan. Detailed list of stakeholders on provincial level are included in the Annexes. Finally, section six gives an overview of the relevant research and previous and existing activities in bioenergy sector in Pakistan.

2 PAKISTAN COUNTRY STATUS

In 2013 Pakistan reached a total population of more than 182 million people, with roughly two thirds of the population residing in rural areas. Population growth rates have remained steady between 1.7 percent and 1.9 percent over the last ten years. In 2013 population growth was recorded at 1.7 percent. The country covers a total of 79,610 thousand hectares. Out of the total land area, 34 percent is classified as agricultural land and 2 percent as forest land.

With steady population growth, income has also been rising over the last 10 years, reaching GDP/capita of US$ 1,386/capita in 2013/14. On the other hand, growth has been declining over the years from 7.5 percent in 2003/04 to 4.1 percent in 2013/14, (Government of Pakistan, Ministry of Finance, 2014). The agriculture sector remains a key sector of the Pakistan economy, despite the persistently falling share of agriculture in GDP going from 24 percent in 2003/04 to 21.0 percent in 2013/14, (Government of Pakistan, Ministry of Finance, 2014). During 2013/14, the agriculture sector witnessed a fall in growth, with a growth rate of 2.1 percent compared with 2.9 percent in the previous year. The decline in growth was due to a fall in the rice and cotton production, which was partially compensated with a better performance of wheat and sugarcane crops. Commercial dairy production has been an emerging sector over recent years, generating employment and additional income for rural population and small farmers.

With steady economic growth, poverty and undernourishment have been declining over time from 24 percent in 2004/05 to 12.4 in 2010/11. Although overall poverty appears to have improved, rural urban disparities remain. For instance, poverty headcount comes around 7.1 percent in urban areas and 15.1 percent in rural areas in 2012/13 against 14.9 percent and 28.1 percent respectively in 2004/05, (The World Bank, 2014).

In percentage terms, undernourishment has been declining from 19 percent between 2008 and 2010 to 17.2 percent in 2011-2013. From an actual population point of view, the number of people undernourished initially increased between 1990 and 2002 but then started declining. In absolute terms, the number of undernourished is now 31 million people.

Total average calorie consumption was 2,428 calories/capita/day in 2011. The food stuffs that contributed the most to daily calorie intake in 2011 are wheat (37 percent of total calories), milk (13 percent of total calories), sugar (10 percent of total calories), palm oil (7 percent of total calories) and rice (5 percent of total calories), (FAOSTAT, 2014a). These five commodities provided 72 percent of the total calories consumed. This illustrates that any consideration around wheat, sugarcane, palm oil and rice for bioenergy use needs to be closely assessed against current and future food needs and available areas of production. At the same time, the residues arising from the production and processing of these crops may be a stable source of bioenergy feedstock.

In the context of agricultural exports, the main export crops in 2009 were rice, wheat and tomatoes. These three commodities provide 63 percent of total export value, by contributing 42 percent, 14 percent and 7 percent respectively. In the case of wheat, Pakistan fluctuates between being a net importer and a net exporter depending on the year and relative production.

According to the Energy Balance published by the International Energy Agency (IEA), the total primary energy supply was 85,820 ktoe in 2011 (IEA, 2014). Primary energy supply is mostly sourced from fossil fuels including natural gas, coal, crude oil and oil products. Fossil fuels supply in total 61.4 percent of primary energy, with domestically sourced natural gas contributing 31.4 percent alone. The second largest energy source is biofuels and waste, i.e. biomass, which contributes 34.2 percent to primary energy supply. The available information on energy supply indicates no or only limited use of modern bioenergy. Therefore, it is reasonable to assume that the stated supply refers to traditional biomass. Hydro and nuclear contribute much smaller shares, 2.4 percent and 1.6 percent respectively, (Figure 1 and Figure 2).

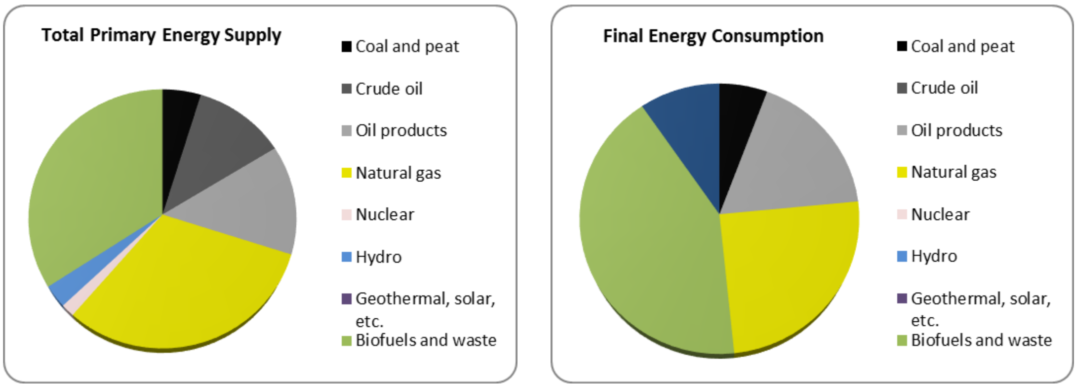

Figure 1: Total Primary Energy Supply (left) and Final Energy Consumption (right) in Pakistan in 2012 according to primary energy sources (IEA, 2014)

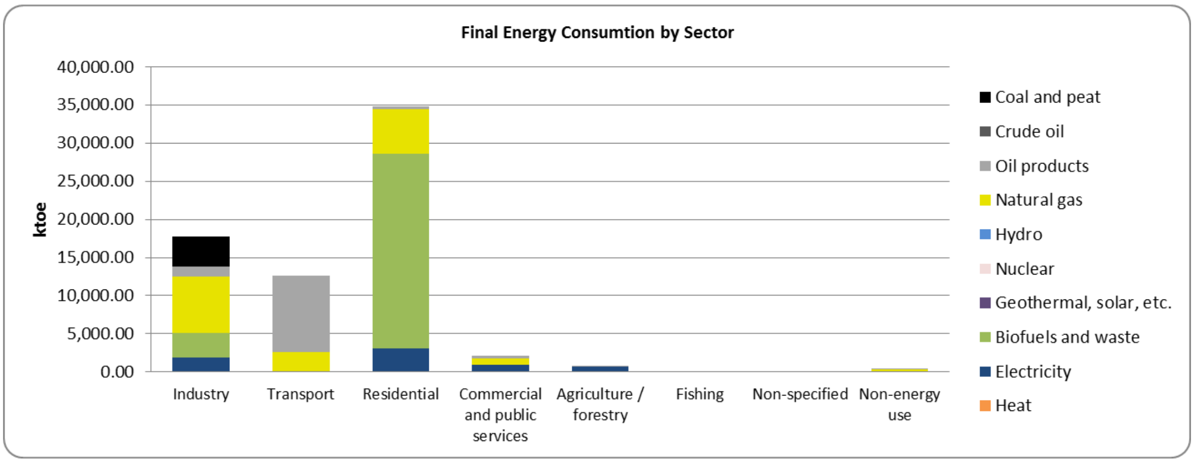

Figure 2: Final Energy Consumption by Sector and Primary Energy Supply in Pakistan in 2012 (IEA, 2014)

The statistics on the primary energy supply in 2011-2012 published in The Pakistan Energy Yearbook 2012, (Hydrocarbon Development Institute of Pakistan, 2013), differ somewhat from the Pakistan Energy Balance published by the International Energy Agency (IEA), (IEA, 2014). It reports that the total primary energy supplies from fossil fuels and electricity (nuclear, hydro and imported) was 64,727 ktoe, (Figure 3). The differences in primary energy supply totals are the result of different reporting systems. The reporting system illustrated in the Pakistan Energy Yearbook does not account for the energy supplied from biomass and waste. Thus, fuelwood, charcoal, biogas and other types of biofuels and wastes are not recorded. When comparing the national statistics on woodfuel production and FAO estimations, there is also a considerable difference. The national statistics indicate that firewood production was 78,000 cubic meters in 2009-10 (Pakistan Bureau of Statistics, 2014), while FAO's estimation of woodfuel[1] production for the same period is 29.7 million cubic meters. The Pakistan Energy Yearbook, on the other hand, reports industry and transport sectors as the main energy consumers, followed by the residential sector (Figure 4).

[1] Includes both total wood used for energy purposes, i.e. firewood and wood used for charcoal production.

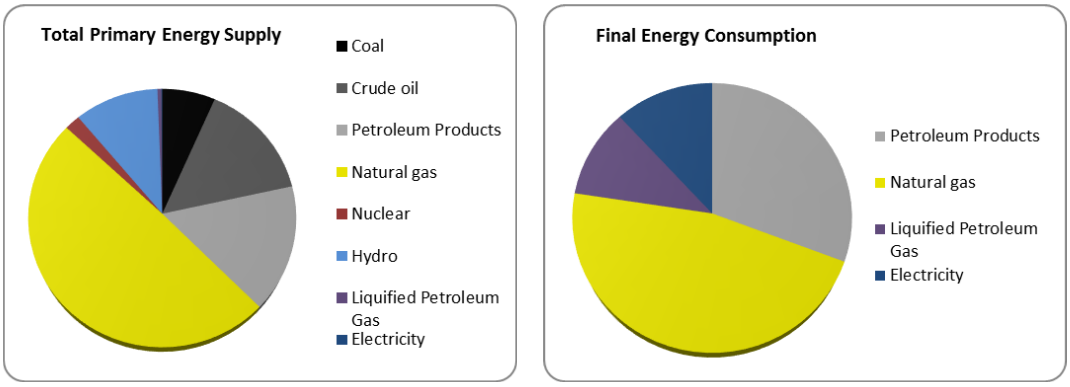

Figure 3: Total Primary Energy Supply (left) and Final Energy Consumption (right) in Pakistan in 2012 according to primary energy sources (Hydrocarbon Development Institute of Pakistan, 2013)

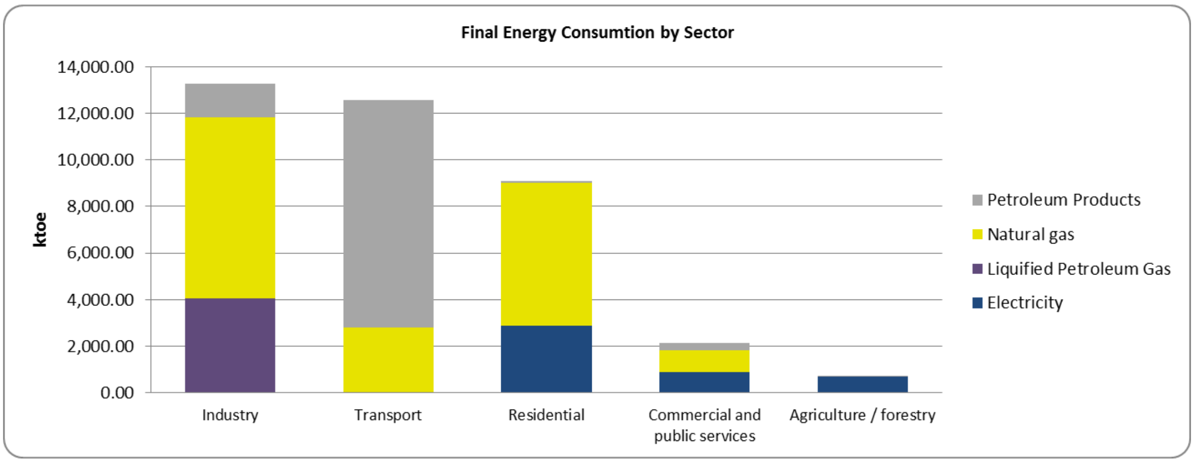

Figure 4: Final Energy Consumption by Sector and Primary Energy Supply in Pakistan in 2012 (Hydrocarbon Development Institute of Pakistan, 2013)

When looking at final energy consumption, according to the IEA, the residential sector is the main consumer of energy. The residential sector consumes 34.8 Mtoe of energy and 74 percent of this is supplied through biofuels and waste, while natural gas and electricity contribute with 17 and 9 percent, respectively. Industry relies on natural gas for about half of its demand, followed by coal, biofuels and waste, electricity and oil products. Even in this sector, biomass is an important source of energy, supplying 18 percent of the consumption. The transport sector is the third consumer of energy, sourced from oil products and natural gas.

Even though the Pakistan Energy Yearbook includes a chapter on renewable energy, the renewable energy sources are still not recorded when reporting on the country's energy balance. In order to have a reference baseline, it will be necessary to record bioenergy sources, levels and uses. Information policy will support decision-making about the appropriate measures for improving the sustainability of current supply and consumption, and subsequently potential sources for additional supply.

Average energy use per capita sharply increased over the last ten years up until 2007 and then declined continuously over the following four years. This is probably due to supply shortage problems and to the increasing population. In 2011, average energy use per capita was recorded at 482 ktoe per capita. Average electricity consumption per head was 457 kwh/capita in 2010, with approximately two thirds of the population having access to electricity.

3 METHODOLOGY FOR BIOMASS RESOURCE ASSESSMENT AND MAPPING

3.1 Biomass as energy resource

Biomass is a versatile resource that can be converted to solid, liquid and gaseous biofuels. Biofuels can either be used directly by energy consumers, for example for heating and cooking, or converted into electricity and then supplied to the consumers.

Biomass resource assessments are used to calculate the biomass potential for energy production. The biomass potential is the quantity of biomass materials that are potentially available for energy production. When the assessment is spatially defined the biomass potential can then be mapped.

Biomass can be used for a number of energy end use options, i.e. electricity generation, heat and power and as a fuel in the transport sectors. Each of these energy end use options has a number of bioenergy pathways that can supply the energy end use type. A bioenergy pathway is characterized by a bioenergy feedstock, i.e. a biomass type, a conversion technology, a biofuel type, a final energy type and then a final energy consumption type. Examples of different bioenergy pathways from the same feedstock are pellets from straw used for heating or electricity produced through gasification of straw. Figure 5 depicts the diversity of bioenergy pathways.

When conducting the biomass resource assessment, first it is necessary to define the energy end use option. This will define the scope of the assessment and the feedstock types to be mapped.

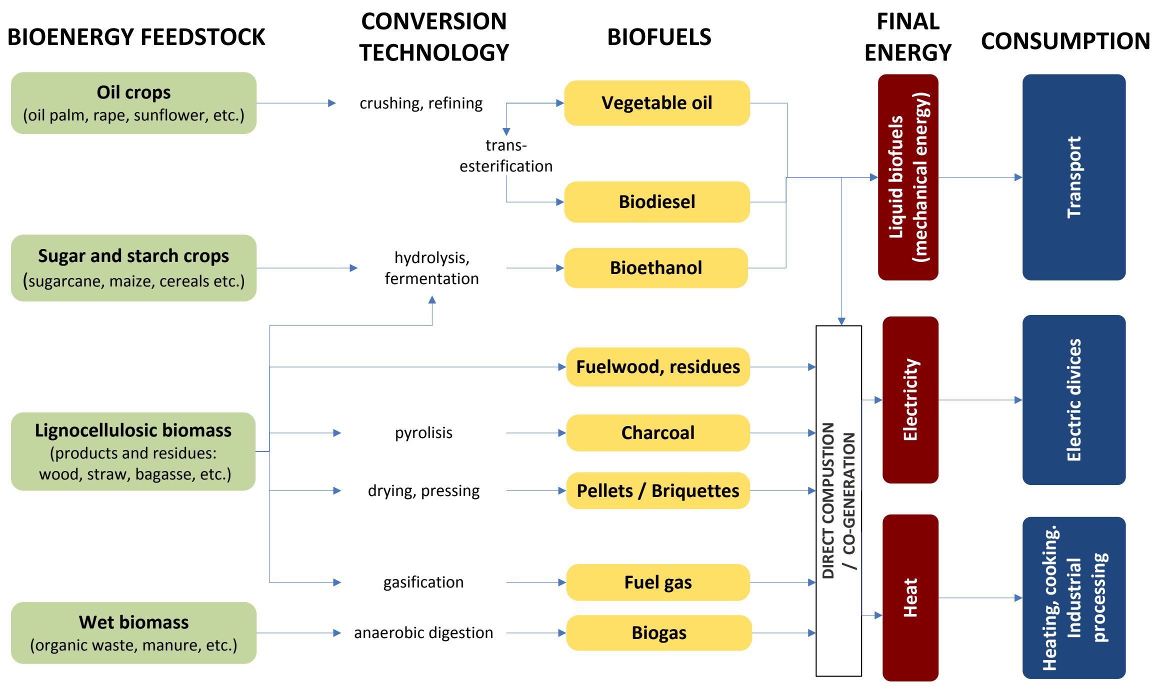

Figure 5: Bioenergy pathways (Adopted from AEBIOM, 2014)

In Figure 5, the bioenergy feedstock types are grouped according to their physical and chemical characteristics, into oil, sugar and starch crops, lignocellulosic biomass and wet biomass. Biomass can be produced from the agriculture, forestry and industry sectors or from waste. Table 1 below illustrates the types of biomass that are sourced from the forestry, agriculture and industry sectors and from waste. At the onset of the biomass resource mapping there needs to be a clear identification which bioenergy pathways are of interest and for which energy end use options. This defines which biomass types are to be considered and which type of data will need to be assessed and mapped.

Table 1: Examples of biomass types according to the supply sector (adopted from FAO, 2004a)

Supply sector	Biomass type	Example
Forestry	Woodfuel	Wood from forests, dedicated woodfuel plantations (including short rotation plantations), trees outside forests, used as fuelwood, or production of charcoal, briquettes, pellets.
	Forest harvesting /pruning/thinning residues	Branches, upper logs and chips and different cut-offs.
Agriculture	Oil, sugar and starch crops	Oil palm, soybean, rapeseed, sunflower (for SVO and biodiesel), sugarcane, sugarbeet, sweet sorghum (ethanol), maize, wheat (ethanol).
	Crop residues	Straw, stover, prunings, huks, cobs, stalks.
	Livestock residues	Manure
Industry	Wood processing residues	Sawdust, cuttings, bark
	Food processing residues	Residues and wastes from slaughterhouses, dairies, breweries and other food processing facilities.
	Other industries	Woody waste from process inputs, packaging.
Waste	Construction waste	Timber formwork, poles, window frames.
	Sewage sludge	
	Municipal waste and other waste	Organic part of the municipal waste.

3.2 Biomass resource potential

Biomass resource assessments estimate the biomass potential. There are four types of biomass potential that can be calculated. The definition of which biomass potential is to be considered is another important element of the analysis as this defines the approach required, the methodology and the data needs (Vis, van den Berg, 2010).

The four types of biomass potential commonly distinguished are:

1. Theoretical potential – the overall maximum amount of terrestrial biomass which can be considered theoretically available for bioenergy production within fundamental bio-physical limits.
2. Technical potential - the fraction of the theoretical potential which is available under the regarded techno-structural framework conditions with the current technological possibilities (such as harvesting techniques, infrastructure and accessibility, processing techniques).
3. Economic potential - The economic potential is the share of the technical potential which meets criteria of economic profitability within the given framework conditions. It generally refers to secondary bioenergy carriers, i.e. biofuels.
4. Implementation potential - The implementation potential is the fraction of the economic potential that can be implemented within a certain time frame and under concrete socio-political framework conditions, including economic, institutional and social constraints and policy incentives. Studies that focus on the financial feasibility or the economic, environmental or social impacts of bioenergy policies are also included in this type.

In practice, if the aim is to assess the *theoretical potential*, the assessment will estimate all biomass produced in the area analysed. While in the *technical biomass potential* the results will represent biomass available and accessible for energy production. This general categorisation of the biomass potential can be further refined. When the assessment methodology includes certain sustainability criteria, due to which the biomass available for bioenergy production is reduced. This potential can be considered to be the *sustainable technical potential*. The biomass potential that is calculated according to FAO's Bioenergy and Food Security approach does not include biomass used for other purposes e.g. part of forest harvesting residues and crop residues important for maintaining soil fertility, or crop residues used for feed and bedding, etc., and also excludes biomass that is not accessiblee.g. manure generated in pasture, which cannot be collected.

3.3 Biomass resource assessment

The methodology required for the biomass resource assessment is specific to each biomass type because of the differences in bio-physical characteristics, production and use. Thus, different parameters are relevant for estimating their availability for energy production. In this document the methodologies applied for the assessment of crop residues, livestock manure, woodfuel, forest harvesting residues and wood processing residues are described.

The described methodologies are based on the best practices for biomass resources assessment (Vis, van den Berg, 2010; Rosillo-Calle et al, 2008) and FAO's Bioenergy and Food Security (BEFS) Approach. The BEFS Approach emphasises the importance of food security and environmental sustainability for development of the bioenergy sector. Therefore, food security and environmental sustainability criteria are integrated and the assessment results represent "sustainable technical potential".

3.3.1 Crop residues

Crop residues are parts of cultivated plants which are not used for the main purpose of the plants' cultivation. Residues are categorized as primary or secondary depending on the location where they are generated. The residues generated in the field during harvesting or pruning, such as straw, stalks, stover and orchard pruning residues, are primary residues. Residues generated during crop processing are known as secondary residues. For example, rice husk, sugarcane bagasse and maize cobs are secondary residues.

The total amount of residues generated in an area is directly related to the production of crops and the efficiency of crop processing, in case of secondary residues. Thus, the *theoretical potential* is based on the total amount of crop production in the area and the respective residue-to-crop ratio (RCR).

The calculations are as follows

$$CR_{tot} = P * RCR \qquad (1)$$

Where:

CR_{tot}, [t/year]	= total crop residue produced in the assessed area
P, [t/year]	= crop production
RCR	= residue-to-crop ratio

On a per-hectare basis, the calculations are as follows:

$$CR_{ha} = C_{ha} * RCR \qquad (2)$$

Where:

CR_{ha}, [t/ha]	= crop residues produced per hectare
C_{ha}, [t/ha]	= crop yield (production per hectare)
RCR	= residue-to-crop ratio

The RCR is the ratio of the amount of residues generated per an amount of main crop product. In the case of wheat straw, RCR represents tons of straw generated per ton of wheat harvested. RCR ratio is species and variety specific. It can also vary within the same variety, due to different agricultural practices, input levels and prevailing agro-climatic conditions during the growing period. Therefore, the accuracy of residues produced is correlated with the accuracy of the RCR.

When calculating theoretical potential of crop residues in an area, it is recommended to use the RCR characteristic for that area. When the area of assessment encompasses a number of farms and/or fields where different conditions may prevail, it is best to use average RCR value. If farm specific RCR values are available, a weighted average should be used. In addition, RCR may be different from one cropping season to the other due to differences in weather conditions. This applies especially in the case of rain-fed agriculture. Thus, it would be optimal to take into account RCR values over a longer period of time, assuming that the same variety was produced and the same agricultural practice applied.

Crop residues are an important source of nutrients and organic carbon in the soil and therefore a certain amount should be left in the field to maintain soil fertility and stability. They are also used for other purposes, such as animal feed and bedding, as construction material, fuel, etc. Diversion from current uses to energy production may have negative socio-economic impacts, especially on poor farmers who use residues as no- or low-cost resource. According to the BEFS approach these residues should not be considered as available for energy production, and therefore the respective amount should be subtracted from the total residues generated[2].

Finally, to calculate sustainable technical potential, the accessibility of the residues should be considered, i.e. the percentage of the crop residues that can be accessed, collected and supplied to the bioenergy production facilities.

The sustainable technical residue potential can be calculated using the formula:

$$CR_{be} = (CR_{tot} - CR_{soil} - CR_{used}) * k \tag{3}$$

Where:

CR_{be}, [t/year] = crop residues available for bioenergy production in the assessed area
CR_{soil}, [t/year] = amount of residues that should be left in the field
CR_{used}, [t/year]= amount of crop residues used for other purposes
k,[%] = accessibility coefficient

The amount of residues which should be left in the field depends on the soil type and structure (content of soil organic carbon, nutrients, rock weathering), level of inputs (chemical, organic fertilizers), agricultural practice (crop rotation, tillage) and the crop cultivated (nutrient uptake, content of nutrients in the residues and root system).

The amount of residues used for other purposes depends on the availability of other resources, activities and the socio-economic conditions of the population in the area. Thus, the CR_{used} is locally specific.

The accessibility coefficient is determined by a number of parameters, such as harvesting method and type of machinery used (if any), labour availability for residues collection, existence and type of transport infrastructure, existence and size of storage facilities in the area, etc. The accessibility of residues is of high importance in determining the optimal location of placing a bioenergy facility and its economic viability.

To express the energy potential of the available residues, the amount of residues is multiplied by its specific low heating value:

$$CR_{be}\,[GJ/year] = CR_{be}[t/year] * LHV[GJ/t] \tag{4}$$

Where:

CR_{be}, [GJ/year] = energy potential of crop residues available for bioenergy production in the assessed area
CR_{be}, [t/year] = crop residues available for bioenergy production in the assessed area
LHV [GJ/J] = low heating value of the crop residue assessed

[2] This approach is valid for the assessment of residues currently available. In case of scenario analysis, the amount or residues used can be altered. This then requires analysis of potential impacts and definition of mitigation measures.

3.3.2 Livestock residues

Livestock manure can be used for the production of biogas, which can then be used in the same manner as natural gas, i.e. for heating and cooking or electricity production. Anaerobic digestion is a good practice for manure management, because the methane[3] which would otherwise be released into the atmosphere is captured and used as energy. At the same time, the utilization of manure as fertilizer is not diminished, but on the contrary is improved. Bio-slurry (digestate), a “by-product” of biogas production, is a higher quality fertilizer in comparison to fresh or composted manure. The concentration of nutrients is higher and the risk of spreading pathogens and xenobiotics is lower due to thermal treatment of manure during the anaerobic digestion.

Biogas can be produced through mono-digestion or co-digestion of organic materials (e.g. manure maize silage, grasses, and slaughterhouse waste). The amount of biogas produced per ton of feedstock and its methane content depend on the biogas production potential of the feedstock and the technology of production. Type of digestion (mesophilic or thermophilic) and stability of the process will be determined by the technology and operation of the process.

The methodology described in this section focuses on the assessment of manure available for biogas production originating from cattle and poultry.

Cattle

The amount of manure available for biogas production is calculated as a sum of collectable manure produced in the assessment area. It is neither practical nor cost-effective to collect manure spread across grazing land. Thus, the existing cattle feeding system should be taken into account when carrying out the assessment.

The following formulae can be used to calculate the amount of cattle manure available for biogas production:

$$MC_{be} = MC_{st} + MC_{stg} + MC_{sg} \tag{5}$$

Where:

MC_{be}, [t/year] = total amount of cattle manure available for biogas production per year

MC_{st}, [t/year] = amount of manure from cattle in *stable only* feeding system

MC_{stg}, [t/year] = amount of manure from cattle in *daily stable/grazing* feeding system

$\mathrm{MC_{sg}}$, [t/year] = amount of manure from cattle in *seasonal grazing* feeding system

Note: Manure originating from cattle in *year-round grazing* is not considered.

The amount of manure produced by cattle in *stable only* feeding system:

$$\mathrm{MC_{st}} = \mathrm{C_{st}} * k * 365 * 1000 \tag{6}$$

Where:

C_{st} [LU or TLU or head] = animals with daily stable only feeding systems, expressed in livestock unit (LU), tropical livestock unit (TLU) or heads

k, [kg/day] = kg of manure produced per day per LU, TLU or head (the unit has to correspond to the unit used for C_{st})

[3] Global Warming Potential (GWP) of methane is 21 times higher than that of carbon dioxide.

The amount of manure produced by cattle in *daily stable/grazing* feeding system:

$$MC_{stg} = C_{stg} * k * 365 * 500 \qquad (7)$$

Where:

C_{stg}, [LU or TLU or head] = animals with daily stable/ grazing feeding systems expressed in livestock unit (LU), tropical livestock unit (TLU) or heads

The amount of manure produced by cattle in *seasonal grazing* feeding system:

$$\mathrm{MC_{sg}} = \mathrm{C_{sg}} * \mathrm{k} * (365 - \mathrm{g} * 30) * 1000 \qquad (8)$$

Where:

C_{sg}, [LU or TLU or head] = animals spending part of the year in pasture, expressed in livestock unit (LU), tropical livestock unit (TLU) or heads

g = number of months spent in pasture

The assessment should be conducted for each cattle species/type (buffalo, dairy and beef cattle), using species specific parameters (number of animals and daily production of manure).

Note that the amount of manure produced daily (k_i in *Formula* x) depends on the size, age and nutrition of animals. So, it is very important to use the same unit for expressing number of animals in the area of assessment and their daily production of manure.

The energy potential in the assessment area is calculated as a sum of energy potential of manure produced by all cattle species.

$$MC_{be} = LHV_{CH_4} * \sum MC_{bei} * VS_i * B_{oi} \qquad (9)$$

Where:

MC_{be}, [MJ/year] = energy potential of cattle manure available for biogas production per year

VS_i [%] = percentage of volatile solids in manure (species specific)

bo_i [Nm^3 of CH_4/kg of VS]= methane production potential of the manure (species specific)

LHV_{CH_4} [$\mathrm{MJ/m^3}$] = low heating value of methane (35.8 MJ/Nm^3)

Poultry

The amount of manure produced by poultry (e.g. chickens, turkeys, etc.) is calculated as a product of number of heads and annual manure production per head/LU/TLU. The assessment should be conducted for each poultry species (e.g. chickens, turkeys, etc.), using species specific parameters (number of animals and daily production of manure).

$$MP_{\mathrm{be}} = P * k * 365 * 1000 \qquad (10)$$

Where:

MP_{be}, [t/year] = total amount of poultry manure available for biogas production per year

P = number/LU/TLU of animals in the assessment area

k, [kg/day] = kg of manure produced daily per head/LU/TLU of poultry animals

Due to the fact that daily manure production per fowl animal is very small, only the production of a large number of animals in one location is considered. The methodology assumes that all manure can be collected. Thus, free-range and garden-bred animals should not be considered.

Note that the amount of manure produced daily (k_i in *Formula* x) depends on the size, age and nutrition of animals. So, it is very important to use the same unit for expressing number of animals in the area of assessment and their daily production of manure.

Finally the energy potential in the assessment area is calculated by summing the energy potential of manure produced by all poultry species.

$$MP_{be} = LHV_{CH_4} * \sum MP_{bei} * VS_i * B_{oi} \qquad (11)$$

Where:

MP_{be},[MJ/year] = energy potential of poultry manure available for biogas production per year

VS_i [%] = percentage of volatile solids in the manure

bo_i [m³ of CH_4/kg of VS]= methane production potential of the species' manure

LHV_{CH_4} [MJ/m³] = low heating value of methane (35.8 MJ/Nm³)

3.3.3 Forest harvesting residues

Forest harvesting residues are parts of felled trees which are not removed from the forest. The rate of removal varies among forests and usually depends on the cost-effectiveness of removing the trees and the type of end product for which the wood is used. In the case of industrial roundwood, upper logs, branches and different cut-offs are often left in the forest, while the stems are removed. Sometimes, stems are also debarked before the removal. In the case of woodfuel, the rate of removal is usually higher, as the smaller branches, cut-offs and bark can be used as fuelwood, or for production of briquettes, pellets or chips. The use of forest harvesting residues for energy can increase energy access and/or substitute the unsustainably harvested fuelwood or other more costly fuels.

The assessment methodology presented here is based on the annual roundwood production, rate of felling removal and the percentage of the residues that are already used. Thereby, it is assumed that tree foliage, small branches and stumps are left in the forest for soil fertilization and protection and biodiversity conservation.

The total amount of harvesting residues is calculated as:

$$TR = TR_{IRW} + TR_{WF} = Rirw * \frac{IRW}{Rirw} + Rwf * \frac{WF}{Rwf} \qquad (12)$$

Where:

TR, [m³/year] = total amount of residues per year
IRW, [m³/year] = industrial roundwood production per year
WF, [m³/year] = woodfuel production per year
R_{irw}, [%] = rate of industrial roundwood felling removal
R_{wf}, [%] = rate of woodfuel felling removal

The foliage is calculated as:

a) for industrial roundwood

$$fol_{IRW} = (TR_{IRW} - b * IRW) * f \quad (13)$$

b) for woodfuel

$$fol_{WF} = TR_{WF} * f \quad (14)$$

Where:

fol, [m^3/year] = amount of foliage from harvesting of industrial roundwood and woodfuel
fol_{IRW}, [m^3/year] = foliage arising from harvesting of industrial roundwood
fol_{WF}, [m^3/year] = foliage arising from harvesting woodfuel
f, [%] = foliage : crown ratio
b, [%] = bark : stem ratio

The branches and various cut-offs are calculated as:

a) for industrial roundwood

$$BC_{IRW} = (TR_{IRW} - b * IRW) - fol_{IRW} \quad (15)$$

b) for woodfuel

$$BC_{WF} = TR_{WF} - fol_{WF} \quad (16)$$

Where:

BC_{IRW}, [m^3/year] = branches and various cut-offs arising from harvesting of industrial roundwood
BC_{WF}, [m^3/year] = branches and various cut-offs arising from harvesting of woodfuel
$B_{IRW} = b * IRW$, [m^3/year] = bark arising from harvesting of industrial roundwood
fol_{WF}, [m^3/year] = foliage arising from harvesting woodfuel
f, [%] = foliage : crown ratio
b, [%] = bark : stem ratio

The amount of forest harvesting residues available is calculated as:

a) for industrial roundwood

$$FHR_{IRW} = (BC_{IRW} + B_{IRW} - FHR_{IRWu}) * coll_{IRW} \quad (17)$$

b) for woodfuel

$$FHR_{WF} = (BC_{WF} - FHR_{WFu}) * coll_{WF} \quad (18)$$

Where:

FHR_{IRW},[m^3/year] = residues available arising from industrial roundwood harvesting
FHR_{WF},[m^3/year] = residues available arising from woodfuel harvesting
FHR_{IRWu},[m^3/year] = currently used residues arising from industrial roundwood harvesting
FHR_{WFu},[m^3/year] = currently used residues arising from woodfuel harvesting
$coll_{IRW}$,[%] = collectability rate for industrial roundwood harvesting residues
$coll_{WF}$,[%] = collectability rate for woodfuel harvesting residues

3.3.4 Wood Processing Residues

The calculation of the available processing residues from sawmills is based on the annual sawnwood production, average efficiency of sawmills in the country and the portion of residues already used.

First the roundwood used for sawnwood production is calculated based on the average recovery rate of sawmills (sawnwood output: roundwood input ratio). Then by applying the output: input ratio, the volumes of sawdust and slabs and chips arising during sawnwood production are determined. By subtracting the portion currently used, the amounts of sawdust and slabs and chips potentially available for bioenergy are determined.

The roundwood used for sawnwood is calculated as:

$$IWR_{sw} = \frac{r_{sw}}{SW} \tag{19}$$

The total amount of wood processing residues is calculated as:

$$WPR_{tot} = sd + sc = (r_{sd} * IWR_{SW}) + (r_{sc} * IWR_{SW}) \tag{20}$$

Where:

$IWR_{SW,}$ [t/year] = roundwood used for sawnwood production
$r_{sw,}$ [%] = sawnwood : roundwood ratio (sawmills recovery rate)
SW, [m^3/year] = annual sawnwood production
r_{sd}, [%] = sawdust : roundwood ratio
r_{sc}, [%] = slabs and chips : roundwood ratio

The amount of wood processing residues still available:

$$WPR_{be} = sd_{be} \mp sc_{be} \tag{21}$$

a) for sawdust

$$sd_{be} = sd - sd_u \tag{22}$$

b) for slabs and chips

$$sc_{be} = sc - sc_u \tag{23}$$

Where:

WPR_{be},[m^3/year] = the amount of wood processing residues available for bioenergy
sd_u, [m^3/year] = sawdust currently used
sc_u, [m^3/year] = slabs and chips currently used
sd_{be}, [m^3/year] = sawdust available for bioenergy
sc_{be}, [m^3/year] = slabs and chips available for bioenergy

3.3.5 Municipal Solid Waste

The organic fraction of municipal solid waste (MSW) is also a resource that can be utilized for bioenergy production. Depending on the waste management system, primary collection and final disposal, different processes and conversion technologies can be used. The most common disposal systems of municipal and non-hazardous industrial waste include landfilling, incineration, household/industrial composting and anaerobic digestion. In the case of landfilling and incineration, the waste may be disposed of as unsorted waste (i.e. as a mix of organic and non-organic fractures), while in other cases the organic fraction has to be separated from the other waste prior to treatment. This separation can take place at the location where the waste is generated or upon collection.

The assessment of the energy potential of the MSW is based on the following parameters:

- number of households in the assessed area;
- the average annual amount of waste generated by a household;
- composition of waste (organic fraction, paper, plastics, metal, other) expressed as a percentage by weight:
- rate of collection;
- energy content of waste fractions foreseen for electricity generation (i.e. organic fraction for anaerobic digestion and landfilling, all fractions for incineration).

Biogas and landfill gas production potential

The following formula can be used to assess the amount of organic fraction of the MSW available for energy generation:

$$OMW_{be} = HH * MW_{HH} * O_{MW} * k_{coll} \tag{24}$$

Where:

OMW_{be}, [t/year]	= organic fraction of MSW available for biogas production
HH	= number of households in the assessment area
MW_{HH}, [t/year]	= amount of municipal waste generated per household per year
O_{MW}, [%]	= organic fraction of the municipal solid waste
k_{coll}, [%]	= percentage of households included in the waste collection system

The calculation of the energy production potential depends on the treatment process applied and the conversion technology used.

In the case of biogas production through anaerobic digestion, the next step is to analyse the chemical and physical characteristics of the collected organic fraction. The most relevant parameters are the proportions of liquids and solids, moisture content and biogas production potential. Finally, the potential for electricity generation will depend on the composition of biogas (content of methane in the biogas) and efficiency of the conversion into electricity.

A similar approach is used for the assessment of the potential production of landfill gas. However, the specifics of the landfill gas generation have to be taken into account. Namely, the production of landfill gas is generally not a managed process, but the gas is generated though a natural decomposition process, at a slower pace and in lower amounts per ton of waste compared to anaerobic digestion. The reasons for that are: waste is not uniform - usually the organic and non-organic fractions of MSW are landfilled together; the environment within the landfill is not fully anaerobic; temperature is not controlled; and the waste is not mixed, which would facilitate the degradation process. Therefore, it is also important to consider the characteristics of the non-organic fractions of MSW and other factors that may inhibit the generation of landfill gas. Another important issue is whether the assessment is carried out for a new landfill or an installation of gas collection and utilization systems for an existing landfill. In the latter case, the size and age of the landfill, as well as the volume and content (organic and non-organic fractions) of the landfilled waste will define the potential for energy production.

Incineration of waste

Energy recovery from waste is based on the incineration of waste and utilization of the generated heat for electricity generation or co-generation of electricity and heat. The potential production of electricity from MSW in this way is based on the total amount of waste generated by households and its energy content and, finally, the efficiency of conversion into electricity.

The following formula can be used to assess the energy potential of the MSW available for energy generation:

$$MSW_{ep} = HH * k_{coll} * MW_{HH} * \sum_{i=1}^{n}(MW_{Fi} * LHV_{Fi}) \qquad (25)$$

Where:

MSW_{ep}, [MJ/year] = energy potential of the MSW in the assessment area
HH = number of households in the assessment area
k_{coll}, [%] = percentage of households included in the waste collection system
MW_{HH}, [t/year] = amount of municipal waste generated by a household per year
MW_{Fi}, [%] = percentage of each fraction of the municipal waste (food waste, paper, plastic, metal, wood, etc.)
LHV_{Fi}, [MJ/t] = Low Heating Value of each fraction of municipal waste (food waste, paper, plastic, metal, wood, etc.)

It is important to emphasize that the logistics of the MSW collection, separation and transport play an important role for the profitability of energy production from waste. Generally, urban areas with well-established waste management systems and where inhabitants do not use organic fraction of the MSW for composting have higher potential for energy generation than rural areas. In addition, transport infrastructure is also better developed in urban areas, and therefore the waste supplied to the energy facility can be gathered from the larger area at lower costs.

3.4 Biomass resource mapping

Mapping of the biomass resources refers to the geographical presentation of biomass available and its energy potential in a defined area. Two approaches may be taken to map the biomass resources available for energy production:

1) mapping of results upon running a numerical analysis,
2) running a spatial analysis, using geo-reference data throughout the analysis.

The later approach gives a possibility to visualise each analytical step and see how different parameters affect the availability and potential across the assessment area. By changing values of the parameters used in the analysis different scenarios can be analysed spatially, and the maps can be easily updated if certain parameters change over time. Considering these advantages, we recommend conducting the biomass resource mapping as part of a spatially explicit resource assessment in Pakistan.

In accordance with the analytical steps of the assessment methodology, the content of the map layers are specific for each biomass type. Nevertheless, to enable comparison among biomass types certain mapping parameters should be the same for all maps. These include the format of the map datasets, the geographic coordinate system and projection and the minimal spatial unit and energy unit used to present the energy potential.

The Geographic Coordinate System and Projection is defined by ESMAP: GCS_WGS_1984, with datum at D_WGS_1984 and prime meridian Greenwich. Degree should be used as Angular Unit.

The minimal spatial unit should be defined according to the objective of the mapping and the needs of the targeted users. It often depends on the resources allocated for mapping and the smallest spatial unit for which the baseline data is available. In the case of biomass mapping for Pakistan, we recommend to use the minimal spatial unit as the one used for land cover mapping. In case this is not possible and another unit is defined, it should not be bigger than distinct level.

The data used in the assessment can be stored, and maps produced, in raster or vector format. Each format has certain advantages over the other. General differences between maps produced in vector and format are listed in Table 2, (OrdinanceSurvey, 2014).

Table 2: General differences between vector and raster data

Vector	Raster
- relatively low data volume - faster display - can also store attributes - less pleasing to the eye - does not dictate how features should look in a GIS	- relatively high data volume - slower display - has no attribute information - more pleasing to the eye - inherently stores how features should look in a GIS

3.5 Technologies for power generation using biomass as feedstock4

Power generation from biomass can be achieved with a wide range of feedstock and power generation technologies that may or may not include an intermediate conversion process (e.g. gasification). In each case, the technologies available range from commercially proven solutions with a wide range of technology suppliers (e.g. solid fuel combustion) through to those that are only just being deployed at commercial scale (e.g. gasification). There are other technologies that are at an earlier stage of development and are not considered in this analysis (Figure 6). In addition, different feedstock and technologies are limited or more suited to different scales of application, further complicating the picture.

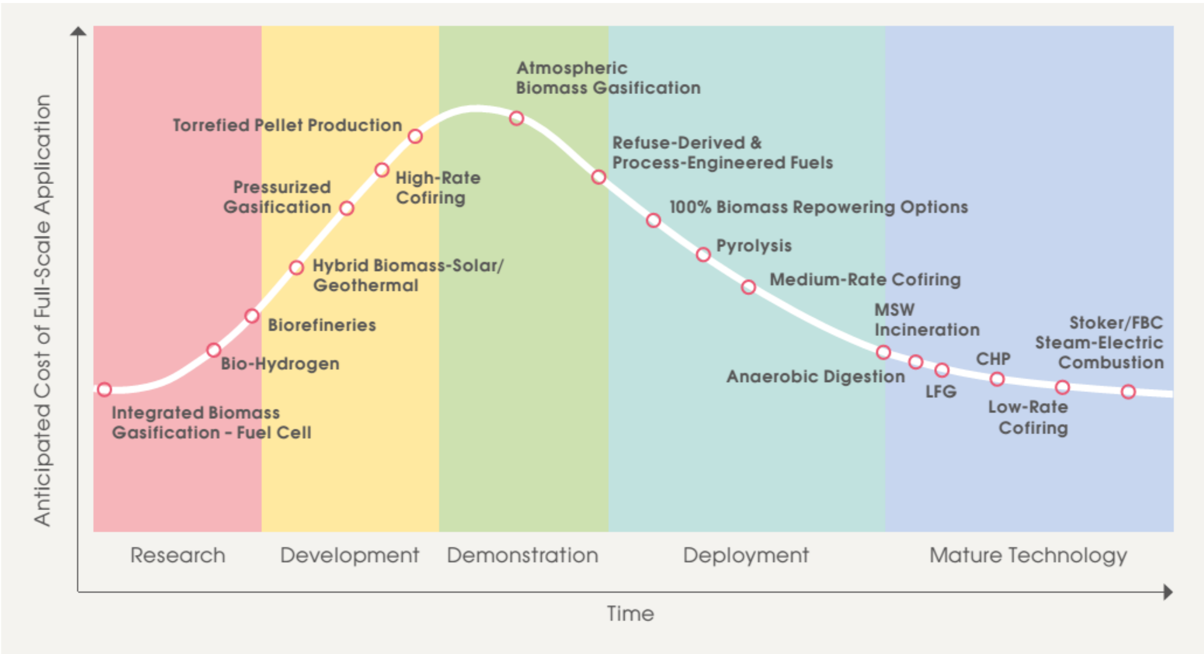

Figure 6: Biomass power generation technology maturity status

3.5.1 Biomass combustion technologies

Direct combustion of biomass for power generation is a mature, commercially available technology that can be applied on a wide range of scales. There are existing systems with installed capacity of a few MW to more than a 100 MW. This is the most wide-spread technology for biomass power generation. Feedstock availability and related logistical costs have a strong influence on the financial viability of such plants, since with increasing scale larger area of feedstock supply is usually needed. High transport costs for the feedstock may outweigh economies of scale from larger plants.

There are two main components of a combustion– based biomass plant: 1) the biomass-fired boiler that produces steam; and 2) the steam turbine, which is then used to generate electricity.

The two most common forms of boilers are stoker and fluidised bed. **Stoker boilers** burn fuel on a grate, producing hot flue gases that are then used to produce steam. The ash from the combusted fuel is removed continuously by the fixed or moving grate. There are two general types of stokers.

[4] Text in this sub-section is extracted from the IRENA Working Paper *"Renewable Energy Technologies: Cost Analysis Series"*, Volume 1: Power Sector *"Biomass for Power Generation"*, (IRENA, 2012).

Underfeed boilers supply both the fuel and the air from under the grate. Overfeed boilers supply the fuel from above the grate and the air from below.

Fluidised bed boilers suspend fuels on upward blowing jets of air during the combustion process. They are categorised as either atmospheric or pressurised units. Atmospheric fluidised bed boilers are further divided into bubbling-bed and circulating-bed units; the fundamental difference between them is the fluidisation velocity (higher for circulating). Circulating fluidised bed boilers (CFB) separate and capture fuel solids entrained in the high-velocity exhaust gas and return them to the bed for complete combustion. Pressurised CFB are available, although atmospheric-bubbling fluidised bed boilers are more commonly used when the fuel is biomass. They can also be a more effective way to generate electricity from biomass with a higher moisture content than typical in a stoker boiler (UNIDO, 2009).

Both types of boilers can be fuelled entirely by biomass or can be co-fired with a combination of biomass and coal or other solid fuels (US EPA, 2007).

Co-firing of biomass with fossil fuels

The co-firing of biomass with coal in large coal-fired power plants is becoming increasingly common. The advantage of biomass co-firing is that, on average, electric efficiency in co-firing plants is higher than in dedicated biomass combustion plants. The incremental investment costs are relatively low although they can increase the cost of a coal-fired power plant by as much as a third.

There are three possible technology set-ups for co- firing (Figure 7):

- Direct co-firing, whereby biomass and coal are fed into a boiler with shared or separate burners;
- Indirect co-firing, whereby solid biomass is converted into a fuel gas that is burned together with the coal; and
- Parallel co-firing, whereby biomass is burned in a separate boiler and steam is supplied to the coal-fired power plant.

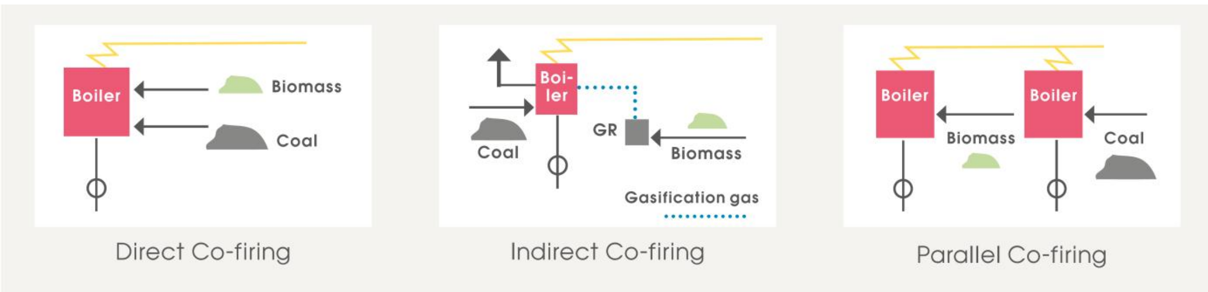

Figure 7: Different biomass co-firing configurations. (Source: EUBIONET, 2003)

Technically it is possible to co-fire up to about 20 percent of capacity without any technical modifications; however, most existing co-firing plants use up to about 10 percent biomass. The co-firing mix also depends on the type of boiler available. In general, fluidised bed boilers can substitute higher levels of biomass than pulverised coal-fired or grate-fired boilers. Dedicated biomass co-firing plants can run up to 100 percent biomass at times, especially in those co-firing plants that are seasonally supplied with large quantities of biomass. However, co-firing more than 20 percent will usually require more sophisticated boiler process control and boiler design, as well as different combustion considerations, fuel blend control and fuel handling systems due to the demanding requirements of biomass-firing and the need to have greater control over the combustion of mixed-feedstock.

Biomass is also co-fired with natural gas, but in this case the natural gas is often used to stabilise combustion when biomass with high-moisture content (e.g. municipal solid waste) is used and the percentage of natural gas consumed is generally low (US EPA, 2007).

Combined heat and power production

Combined heat and power (CHP), also known as a co-generation, is the simultaneous production of electricity and heat from one source of energy. CHP systems can achieve higher overall efficiencies than the separate production of electricity and heat when the heat produced is used by industry and/or district heating systems (Figure 8). Biomass-fired CHP systems can provide heat or steam for use in industry (e.g. the pulp and paper, steel, or processing industries) or for use for space and water heating in buildings, directly or through a district heating network. The viability of biomass CHP plants is usually governed by the price of electricity and the availability and cost of the biomass feedstock. Although many sources of biomass are available for co-generation, the greatest potential lies in the sugar cane and wood processing industries, as the feedstock is readily available at low cost and the process heat needs are onsite (UNIDO, 2008).

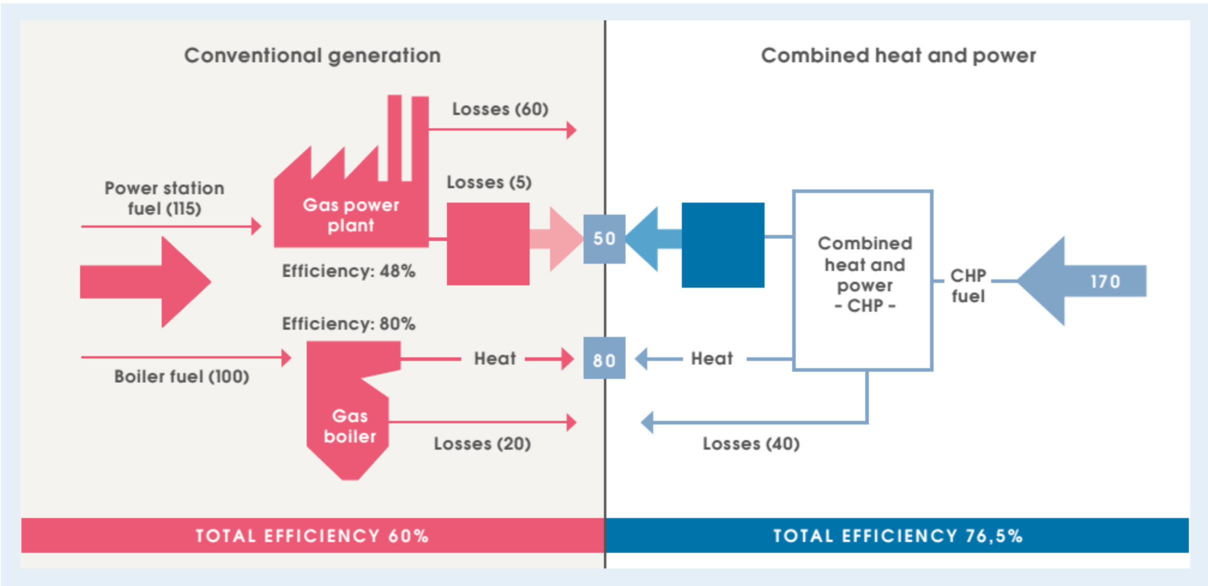

Figure 8: Example of efficiency gains from CHP (Source: Based on IEA, 2008)

3.5.2 Anaerobic Digestion

Anaerobic digestion (AD) converts biomass feedstocks with a relatively high moisture content into a biogas. Anaerobic digestion is a naturally occurring process and can be harnessed to provide a very effective means to treat organic materials, including energy crops (with high moisture and low hemicellulose content), residues and wastes from many industrial and agricultural processes and municipal waste streams. AD is most commonly operated as a continuous process and thus needs a steady supply of feedstock.

The feedstock needs to be strictly checked and usually needs some form of pre-treatment to maximise methane production and minimise the possibility of killing the natural digestion process.

Co-digestion of multiple feedstocks is most commonly practised to achieve the best balance of biogas yield and process stability. The two main products of AD are biogas and a residue digestate, which, after appropriate treatment, can be used as a fertiliser.

Biogas is primarily a mixture of methane (CH_4) and carbon dioxide (CO_2), as well as some other minor constituents including nitrogen, ammonia (NH_3), sulfur dioxide (SO_2), hydrogen sulphide (H_2S) and hydrogen. Biogas is readily used as a fuel in power or combined heat and power units and has the potential to be used as a substitute for natural gas after appropriate cleaning and upgrading (IEA Bioenergy, 2009). Large- scale plants using municipal solid waste (MSW), agricultural waste and industrial organic wastes require between 8 000 and 9 000 tonnes of waste per MW per year.

Collection of landfill gas and its utilisation for electricity production or co-generation are also proven technologies. The installed capacity and annual energy generation depends on the size and age of the landfill, as well as composition of the landfilled waste.

3.5.3 Black Liquor

An important source of electricity generation from bioenergy today is found in the pulp and paper industry in the form of black liquor. Black liquor is a by-product of the paper-making process and consists of the remaining components after cellulose fibres have been “cooked” out of the wood feedstock. Although initially weak (15% solids), this solution is concentrated by evaporation until it has a solid content of around 75 to 80 percent. It can then be combusted in an energy recovery boiler or, less commonly, gasified. The black liquor then provides electricity and heat for the process needs of the plant and possibly for export. Combustion in boilers is a mature technology, but commercial gasification technologies are only just being deployed.

3.5.4 Biomass Gasification

Gasification technologies offer the possibility of converting biomass into producer gas, which can be burned in simple or combined-cycle gas turbines at higher efficiencies than the combustion of biomass to drive a steam turbine. Although gasification technologies are commercially available, more needs to be done in terms of research and development, as well as demonstration to promote their widespread commercial use.

The key technical challenges that require further research and development include improving fuel flexibility, removing particulates, alkali-metals and chlorine; and the removal of tars and ammonia (Kurkela, 2010). From an economic perspective, reducing complexity and costs, and improving performance and efficiency are required.

There are three main types of gasification technology: fixed bed gasifiers, fluidised (circulating or bubbling) bed gasifiers; and entrained flow gasifiers. However, there are a wide range of possible configurations, and gasifiers can be classified according to four separate characteristics:

- Oxidation agent: This can be air, oxygen, steam or a mixture of these gases.
- Heat for the process: This can be either direct (i.e. within the reactor vessel by the combustion process) or indirect (i.e. provided from an external source to the reactor).
- The pressure level: Gasification can occur at atmospheric pressure or at higher pressures.
- Reactor type: As already discussed, these can be fixed bed, fluidised bed or entrained flow.

Gasification comprises a two-step process. The first step, pyrolysis, is the decomposition of the biomass feedstock by heat. This yields 75 to 90 percent volatile materials in the form of liquids and gases, with the remaining non-volatile products being referred to as char. The second step is the gasification process, where the volatile hydrocarbons and the char are gasified at higher temperatures in the presence of the reactive agent (air, oxygen, steam or a mixture of these gases) to produce CO and H_2, with some CO_2, methane, other higher hydrocarbons and compounds including tar and ash. These two steps are typically achieved in different zones of the reactor vessel and do not require separate equipment. A third step is sometimes included: gas clean-up to remove contaminants, such as tars or particulates.

Air-based gasifiers are relatively cheap and typically produce a hydrogen/carbon monoxide "producer gas with a high nitrogen content (from the air) and a low energy content (5–6 MJ/m^3 on a dry-basis). Gasifiers using oxygen or steam as the reactive agent tend to produce a syngas with relatively high concentrations of CO and H_2 with a much higher energy content (9–19 MJ/m^3), albeit at greater cost than an air-blown gasifier.

The gasification process is a predominantly endothermic process that requires significant amounts of heat. The "producer gas", once produced, will contain a number of contaminants, some of which are undesirable, depending on the power generation technology used. Tars, for example, can clog engine valves and accumulate on turbine blades, leading to increased maintenance costs and decreased performance. Some producer gas clean-up will therefore usually be required. After cleaning, the producer gas can be used as a replacement for natural gas and injected in gas turbines or it can produce liquid biofuels, such as synthetic diesel, ethanol, gasoline or other liquid hydrocarbons via Fischer-Tropsch synthesis.

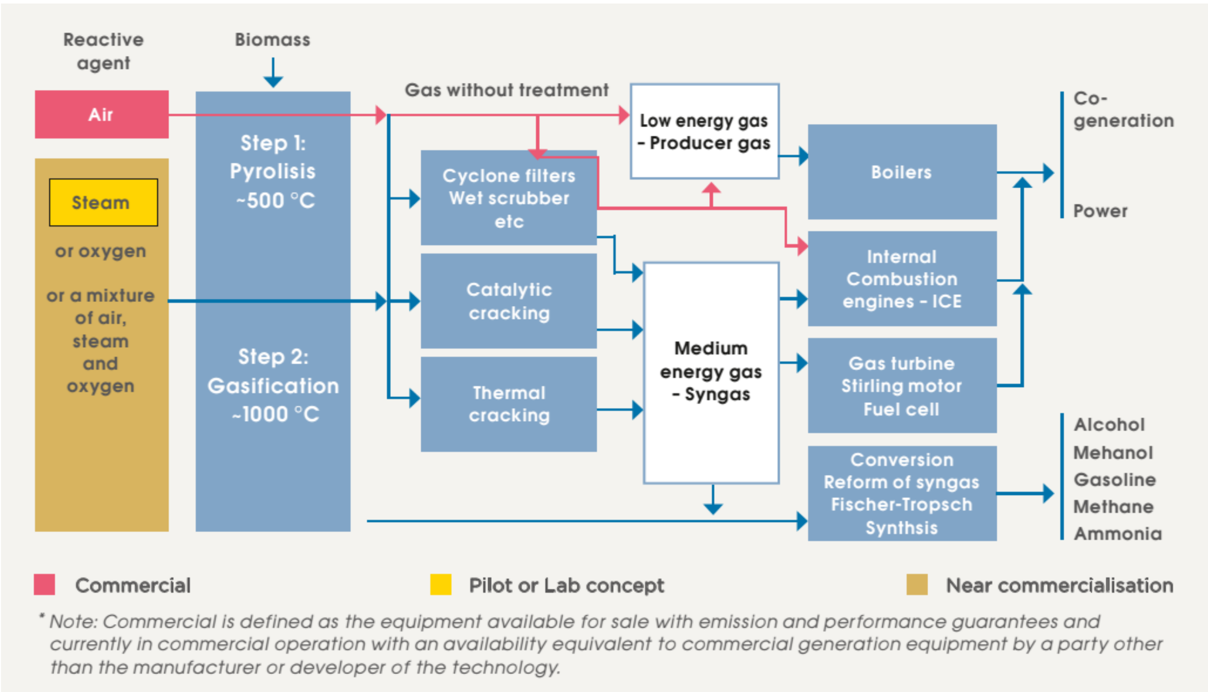

Figure 9: Schematic of the gasification process
(Source: Based on Sadaka,2010, Belggiorno, 2003, and McHale, 2010)

One of the key characteristics of gasifiers, in addition to the producer gas they produce, is the size range to which they are suited. Fixed bed downdraft gasifiers do not scale well above around 1 MW_{th} in size due to the difficulty in maintaining uniform reaction conditions (Lettner, 2007). Fixed bed updraft gasifiers have fewer restrictions on their scale while atmospheric and pressurised fluidised bed and circulating bed, and entrained flow gasifiers can provide large-scale gasification solutions, (Figure 10).

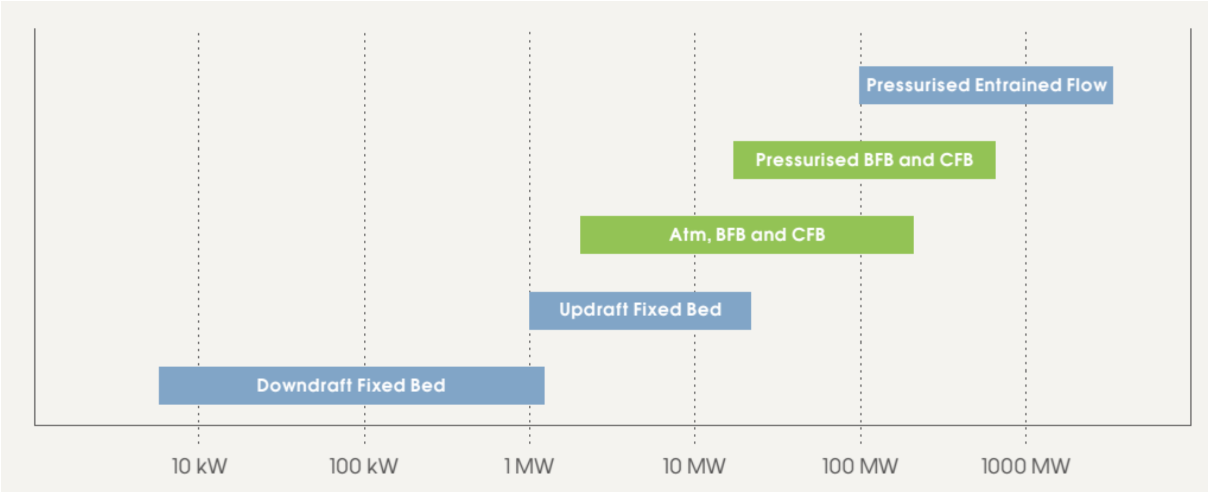

Figure 10:Gasifier size by type (Source: Rensfelt, 2005)

Biomass integrated combined cycle gasification

Biomass integrated combined cycle gasification (BIGCC), or biomass integrated gas turbine technology (BIG-GT), has the potential to achieve much higher efficiencies than conventional biomass-powered generation using steam cycles by creating a high quality gas in a pressurised gasifier that can be used in a combined cycle gas turbine. Significant research and development was conducted and pilot-scale plants were built in the late 1990s and the early 2000s. Several demonstration plants were also built. However, performance has not been as good as hoped for, and the higher feedstock costs for large- scale BIGCC and the higher capital costs due to fuel handling and biomass gasification has resulted in a cooling of interest.

Pyrolysis

Pyrolysis is a subset of the gasification system. Essentially, pyrolysis uses the same process as gasification, but the process is limited to between 300°C and 600°C. Conventional pyrolysis involves heating the original material in a reactor vessel in the absence of air, typically at between 300°C and 500°C, until the volatile matter has been released from the biomass. At this point, a liquid bio-oil is produced, as well as gaseous products and a solid residue. The residue is char - more commonly known as charcoal - a fuel which has about twice the energy density of the original biomass feedstock and which burns at a much higher temperature. With more sophisticated pyrolysis techniques, the volatiles can be collected, and careful choice of the temperature at which the process takes place allows control of their composition. The liquid bio-oil produced has similar properties to crude oil but is contaminated with acids and must be treated before being used as fuel. Both the charcoal and the oil produced by this technology could be used to produce electricity (although this is not yet commercially viable) and/or heat.

4 BIOMASS RESOURCE ASSESSMENT AND MAPPING IN PAKISTAN

4.1 The scope of biomass assessment and mapping

The objective of ESMAP Renewable Energy Resource Mapping in Pakistan is to map the biomass resources available for electricity production. Taking into account the characteristics of the agricultural and forestry sector in Pakistan, combustion, gasification and biogas production have been identified as suitable technologies for electricity production. Combined heat and power production, especially in industries, which have access to bioenergy feedstock and needs for heat, is also a technology to be considered. The biomass types recommended for biomass assessment and mapping and respective conversion technologies are listed in Table 3.

Table 3: Biomass type and conversion technology suitable for electricity production in Pakistan

Supply sector	Biomass type	Conversion technology
Agriculture	Crop residues	Combustion/co-generation, gasification
	Livestock residues	Biogas, biogas to electricity, biogas to electricity and heat
Forestry	Woodfuel, harvesting residues	Combustion/co-generation, gasification
Industry	Wood processing residues (slabs, sawdust, chips generated in saw mills)	Combustion/co-generation, gasification
	Food processing residues (sugarcane bagasse, sugarbeet pulp, rice husk)	Combustion/co-generation, gasification, biogas

In line with the methodology described in the previous chapter, the analytical steps and recommendations for mapping for each biomass type are given in the following sections. In line with the methodology, the required data are explained and possible data sources listed. An overview of the readily available data for Pakistan is given and data gaps identified.

4.2 Crop-residues

4.2.1 Assessment steps, data requirements and data sources

Selection of crop residue types

Considering factors relevant for the establishment of energy facilities, the first step in crop residue assessment and mapping is to determine the residues:

- which are suitable for electricity production,
- which are produced in substantial amounts,
- whose production does not fluctuate considerably over time.

Namely, a secure and stable supply of crop residues is one of the key factors for continuous production of electricity and for financial viability of an electricity production facility. The feedstock transportation costs may have a major impact on the level of operating costs. As a result, the installed capacity often depends on the amount of feedstock available in the vicinity of the facility.

In general, production of most important food and cash crops is more or less stable over time. Therefore, we recommend starting the assessment and mapping with residues of those crops, and eventually add other crop residues according to their relevance. The key food crops in Pakistan are wheat, rice, maize, sorghum (local name: jowar), pearl millet (local name: bajra) and barley. On the other hand, the key cash crops include cotton, tobacco, jute, sugarbeet, sugarcane, guarseed and sunhemp.

A list of residue types originating from these crops that can be used for electricity production though gasification, combustion or biogas production is given in Table 4. Location of residue generation is also indicated for each residue type.

Table 4: Crop residue types suitable for electricity production in Pakistan

Crop	Residue type	Location of residue generation
Wheat	Straw	Spread in the field
Rice	Straw Husk	Spread in the field Processing plant
Maize	Stover Cob Husk	Spread in the field Collected (field, farm, processing facility) Field, collected (field, farm, processing facility)
Sorghum	Stalk	Spread in the field
Pear millet	Stover Cob	Spread in the field Collected (field, farm, processing facility)
Barley	Straw	Spread in the field
Cotton	Stalk	Spread in the field
Sugarbeet	Beet pulp	Sugar processing plant
Sugarcane	Bagasse	Sugar processing plant

Average annual production and production area of the most important food and cash crops for the period 2000-2009 in Pakistan and in each of the four provinces are given in Table 5 and Table 6, respectively. The crops are ranked according to the average annual production quantity.

From the following tables, it is evident that sugarcane, cotton and wheat are the most produced crops in all provinces, except in KPK where sugarbeet is the second most produced crop and wheat the third. The information about the amount of crops produced leads to the conclusion that sugarcane bagasse, wheat straw and cotton stalks will be the most abundant among the selected residues. However, we recommend assessing availability of residues originating from the 5-6 highest ranked crops. Namely, even if not significant on the national or provincial level, the energy potential of less produced crops may be sufficient to supply electricity demand on the local level.

Table 5: Average annual production and area of most important food and cash crops in Pakistan in the period 2000-2009 (Source: Federal Bureau of Statistics, 2010)

Crop	Avg. annual production (000 t)	Avg. annual production area (000 ha)
Sugarcane	50,860,688	1,034,223
Cotton	1,988,568	3,007,856
Sugarbeet	171,227	5,042
Guarseed	118,335	149,355
Tobacco	98,111	49,562
Wheat	20,790	8,385
Rice	5,171	2,486
Maize	2,571	990
Sunhemp	1,414	2,086
Pearl millet	237	443
Sorghum	193	315
Barley	93	99
Jute	22	21

Table 6: Average annual production and area of most important food and cash crops in Punjab, Balochistan, Sindh and KPK in the period 2000-2009 (Source: Federal Bureau of Statistics, 2010)

Punjab			Balochistan		
Crop	Production (000 t)	Production area (000 ha)	Crop	Production (000 t)	Production area (000 ha)
Sugarcane	33,099,356	688,000	Sugarcane	30,519	597
Cotton	1,540,927	2,395,934	Cotton	15,928	34,506
Wheat	16,338	6,360	Wheat	719	358
Rice	2,940	1,694	Rice	448	163
Maize	1,681	468	Barley	22	19
Pearl millet	197	345	Sorghum	22	26
Sorghum	119	209	Maize	5	5
Barley	34	35	Pearl millet	1	1
Sindh			**KPK**		
Crop	Production (000 t)	Production area (000 ha)	Crop	Production (000 t)	Production area (000 ha)
Sugarcane	13,011,511	242,609	Sugarcane	4,719,302	103,018
Cotton	431,219	576,249	Sugarbeet	170,930	5,010
Wheat	2,692	917	Wheat	1,041	750
Rice	1,657	567	Maize	882	513
Sugarbeet	397	42	Cotton	493	1,167
Sorghum	47	73	Rice	126	61
Pearl millet	37	91	Barley	32	34
Barley	5	10	Sorghum	4	7
Maize	3	5	Pearl millet	3	5

The cropping pattern and crop rotation throughout the year and period when residues are available are relevant for interpreting the assessment results and defining the layout of the maps.

There are two cropping seasons in Pakistan, “Khafir” and “Rabi” seasons. Sowing in the “Kharif” season starts in April and harvest takes place between October and December, while the “Rabi” season starts in October-December and ends with harvesting in April-May. Rice, sugarcane, cotton, maize and millet are “Kharif” crops, while wheat, gram, tobacco, rapeseed, barley and mustard are “Rabi” crops, (FAO, 2004b). The growing periods and production regions of the selected crops are depicted in the Figure 11 and Figure 12.

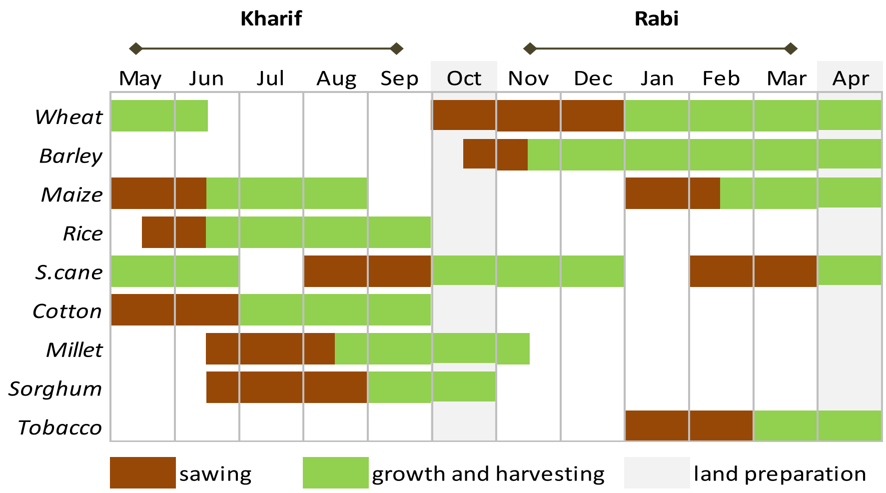

Figure 11: Growing periods of the selected crops in Pakistan (Adapted from: Pakarab, 2014 and GIEW, 2014)

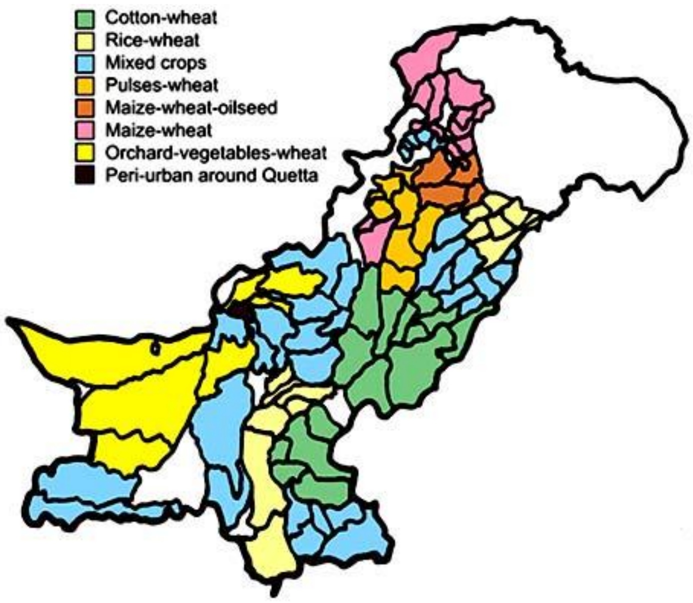

Figure 12: Cropping patterns in Pakistan (Source: FAO, 2004b)

The total amount of crop residues generated

The total amount of residues generated per minimal spatial mapping unit should be calculated by applying *Formula (1)*.

Thereby, it is recommended to use local or district specific RCR. If the RCR values are not available, province level or national values can be used. The RCR values can be obtained directly from crop producers through field surveys and questionnaires. If it is not possible to carry out such surveys, we recommend to use literature source and consult agronomists affiliated to national universities, research institutes and agriculture departments of provincial governments.

The final option is to use global average values, (Table 7). If so, before running the analysis it would be preferred that the selected values are validated with technical experts in the country.

Table 7: Crop residue ratio for selected crops (Source: BEFS Rapid Appraisal)

Crop residue type		Residue to Crop Ratio (RCR)			
crop	residue	average	min	max	stdev
barley	straw	1.35	0.95	1.75	0.27
cotton	hull	0.26	0.26	0.26	0
cotton	stalk	3.40	2.76	4.25	0.47
maize	cob	0.33	0.20	0.86	0.16
maize	husk	0.22	0.20	0.30	0.04
maize	stover	1.96	1.00	3.77	0.67
millet	straw	2.54	1.40	4.00	0.81
rice	straw	1.33	0.42	2.15	0.68
rice	husk	0.25	0.15	0.36	0.06
sorghum	straw/stalk	2.44	1.00	4.60	0.97
sugarcane	tops/leaves	0.20	0.05	0.30	0.10
sugarcane	bagasse	0.26	0.14	0.40	0.07
wheat	straw	1.28	0.50	2.00	0.36

The values presented in Table 7 are based on extensive literature research and used in the FAO's BEFS Rapid Appraisal tool for crop residues assessment, (FAO, 2014). For each crop residue type average, minimum and maximum values are indicated, as well as standard deviation.

When using the global values, one should bear in mind that they represent global averages, which will reflect on the accuracy of the final results. In practice, the residue-to-crop ratio is species and cultivar specific and can be affected by the agricultural management practice, inputs, agro-climatic conditions during the growing period, etc. For example, advanced cultivars usually have a lower RCR than the traditional cultivars. Thus, considering the predominant agricultural practice in crop production, the analyst should decide which residue-to-crop ratio would be the most appropriate to use.

Residues for soil fertility and stability

Residues left in the field after harvest play an important role for maintenance of soil fertility and stability, which is of crucial importance for production of crops. It can be part of a more complex practice, such as conservation agriculture. Often residues are the only source of nutrients a farmer can afford. As indicated earlier, one of the sustainability criteria integrated in the proposed methodology is that a certain amount of residues should be left in the field and therefore not considered as available for bioenergy production, (*Formula 2*). This applies to primary residues, i.e. residues generated in the field.

The amount of residues to be left in the field (CR_{soil} in *Formula 2)* should be defined for each crop residue type, taking into consideration nutrient content in the respective residue, and the soil characteristics in the production area.

Soil maps should be used as a baseline layer for defining the adequate value per minimal spatial unit. The higher the resolution of soil maps, the more accurate values can be defined. Nutrient content in the residues can be obtained through laboratory analysis, from literature or though expert consultation. We recommend contacting experts from national universities and research institutions, and technical officers in the agriculture departments of provincial governments.

In case national soil maps of the assessment area are not available, global maps can be used, such as Harmonized World Soil Database (HWSD), last updated in 2012. This database is from FAO Geo-Network (link: http://www.fao.org/geonetwork/srv/en/main.home) and from IIASA Portal (link: http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/).

In case crop residue and area specific values cannot be determined, we recommend to use 25 percent of total amount generated, (FAO, 2014). Whichever value is used, it is necessary to document it and indicate the source.

Residues currently used for other purposes

According to the FAO's BEFS approach, the residues currently used for other purposes should not be accounted as available for bioenergy production, (CR_{used} in *Formula 2)*. Depending on the type of residues, farming systems (e.g. integrated crop and livestock production) and economic status of farmers, residues can be used as animal feed and/or bedding, construction material, fuel, etc.

The pattern and amount of residues used often differ to a considerable extent within the assessment area. Therefore, it is recommended to conduct field surveys or at least consultations with farmers and experts, in order to define the amount of residues already used.

To our knowledge, such a survey was conducted in several districts of the Punjab Province as part of the study "Development of market based approach for utilization of biomass in industrial power generation", financed by GIZ and prepared by Alternative Energy Solution Providers. If better data is not available for Punjab, these can be used. Due to differences among provinces in Pakistan, for other provinces we highly recommend to conduct equivalent field surveys, or structured interviews and/or technical consultations with the technical officers of the agriculture departments and scientists affiliated to research institutions or universities.

Another important use of crop residues in Pakistan is the pulp and paper industry. The main residues used as raw materials include wheat and rice straw, and bagasse. The representatives of the industry or of the All Pakistan Merchants Association (link: www.appma.com.pk/) should also be consulted during the data gathering. More information can be found in the report "Pulp and Paper Industry in Pakistan", (SECOM, 2012).

Accessibility of residues available for electricity production

The accessibility coefficient is determined by a number of parameters, such as harvesting method and type of machinery used (if any), labour availability for residues collection, existence and type of transport infrastructure, existence and size of storage facilities, etc. Ultimately, the accessibility is very much dependent on the price offered by the energy facility. Considering this and the objective of the biomass resource assessment and mapping in Pakistan, we recommend to assume that all residues available for bioenergy can be collected, i.e. that *k=1* in *Formula (2)*. Thus, the maps developed can be used as a baseline for more detailed analysis at a local level.

Energy potential of residues available for electricity production

For each residue type the energy potential is calculated using *Formula (4).* If country specific LHV for the assessed residues area is not available, global values can be used, (Table 8).

Table 8: Low heating values for selected crop residue types

Crop-residue type		LHV
crop	**residue**	**MJ/kg**
barley	straw	17.38
cotton	hull	17.71
cotton	stalk	17.81
maize	cob	16.57
maize	husk	17.41
maize	stover	15.74
millet	straw	17.22
rice	straw	14.51
rice	husk	14.35
sorghum	straw/stalk	16.38
sugarcane	tops/leaves	13.74
sugarcane	bagasse	16.18
wheat	straw	15.87

4.2.2 Mapping steps, data requirements and data sources

To present the availability of crop residues, we recommend producing a map (layer) for each crop residue type and one layer which will represent the overall energy potential for the minimal spatial unit. Along with the maps, an assessment report and data catalogue should be prepared. The assessment report should include a methodology overview and indicate data sources and parameters used for the assessment. The report should also provide guidance on how to interpret the results presented in the maps. The data catalogue, on the other hand, should include a list of the map layers with a description of variables, indicating the time period for which data are valid and their sources.

For each crop residue type the following layers should be produced:

- total crop residue generation
- amount of crop residue available for electricity production (t/minimal spatial unit)
- energy potential of the crop-residue available for electricity production (joules per minimal spatial unit)

Layer: Total crop residue generated

For mapping of ***primary crop residues (residues generated in the field),*** the baseline layer should include information on the areas used for cultivation of the crop and the respective yields. If such a layer is not readily available, one can be produced using land cover maps or maps of cultivated area and statistical data on the crop production. The datasets needed and possible sources area are described and commented in the following table.

Table 9: Datasets and possible sources for *Total crop-residues generated* layer

Dataset needed	Source of data
Land cover/land use maps - Areas of crop cultivation	Government of Pakistan/Provincial Governments Available: Land Cover Atlas of Pakistan developed and published by FAO, SUPARCO and Crop reporting Service, Government of Pakistan
Annual production (t/ha), production area (ha)	Agricultural statistics Available: Crops area and Production (by District) 1981/82 – 2008/09, published by Government of Pakistan, Statistics Division, Federal Bureau of Statistics
Residue-to-crop ratio	Local, district and/or provincial level surveys and reports. Technical consultations and interviews with agronomist affiliated with the universities, research institutes and agriculture departments of provincial governments. Global data.

The ***secondary crop residues, which are generated in the processing facilities***, should be mapped at the location of the processing plants. Therefore, the first step is to map the locations of the processing facilities. For each location the following information should be included in the report/map layers:

- Location of the processing plant (coordinates)
- Name, main products (vector maps: in the attribute table, raster maps: report)
- Total crop-residue generation
- Amount of crop-residue available for electricity production
- Energy potential of the residues available

The total amount of residues generated in the processing facility can be calculated based on the production capacity of the facility (i.e. how much residues are processed annually) and the respective RCR. The RCR will be based on the efficiency of the plant. In case that the plant-specific RCR values are not available, province or country specific values can be allocated to all processing plants.

The following industries should be mapped: sugarcane crashing facilities for bagasse, sugarbeet processing facilities for beet pulp, rice processing for rice husk.

Table 10: Datasets and possible sources for mapping secondary crop residues

Dataset needed	Source of data
Name, location and production capacity (installed and utilized)	Provincial departments of agriculture and/or industry; industry associations; chambers of commerce.
RCR for each processing plant	Surveys among industries, technical officials of the agricultural departments. Global average values.

Layer: Crop residues available for electricity production

This layer is produced by reducing the total crop residue generated by the amount left in the field and the amount used for other purposes. If the maps are produced in vector format, the information about the amount/percentage of residues used for different purposes may be included in the attribute table of the shapefile. In case of raster maps they should be included in the raster catalogue.

The datasets needed and possible sources are described and commented on in the following table.

Table 11: Datasets and possible sources for *Crop residues available for electricity production* layer

Dataset needed	Source of data
Amount/percentage of residues to be left in the field	Field research and soil analysis. Technical consultations and interviews with agronomists affiliated with the universities, research institutes and agriculture departments of provincial governments.
Amount/percentage of residues used for other purposes	Field survey, technical consultations and interviews with agronomists affiliated with the universities, research institutes and agriculture departments of provincial governments. Interviews and surveys among industries using crop residues as feedstock (e.g. pulp and paper industry, feed producers…). In case of secondary residues, the main source of information should be the industries where the residues are generated. The survey questionnaires should be designed in such a way to identify how much residues or which portion of residues is used for each purpose, how much is burned or disposed.

Layer: Energy potential of the residues available for electricity production

Energy potential of all residue types is summed and presented in this layer. To do so, the amount of each crop residue should be expressed in energy units (*Formula 3*) before summing the potential of all residues. The potential should be allocated to the location of their generation, i.e. for secondary residues at the locations of processing facilities. The datasets needed and possible sources area are described and commented in the following table.

Table 12: Possible sources for *Energy potential of the residues available for electricity production*

Dataset needed	Source of data
Low heating value for each crop residue type assessed and mapped.	Laboratory testing. Literature, technical consultations and interviews with agronomists affiliated with the universities, research institutes and agriculture and energy departments of provincial governments.

4.3 Livestock residues

4.3.1 Assessment steps, data requirements and data sources

Cattle manure

On the household level, biogas is commonly produced for cooking and lighting. Due to the small amount of manure available, the amount of biogas is not sufficient to make electricity production profitable. However, it may be profitable on a community level, when manure produced by a number of households is gathered and biogas is jointly produced. In commercial livestock production, manure is produced in the same location continuously, which makes the operational costs of biogas production lower, in comparison to community level production, and possibly results in higher profitability of electricity production. Due to these differences, the logistics, technology and capacity of production are often different among community and commercial level biogas production. In order to provide an indication of which kind of biogas production is more suitable across the assessment area, the resource assessment (amount of manure available) should be carried out separately for household and commercial livestock production.

The cattle species bred in Pakistan, whose manure can easily be used for biogas production are buffaloes and cows. Most rural households keep buffaloes and cattle for milk production. According to the 2006 livestock census, 51 percent of the 8.4 million reported dairying households owned 1–4 animals, 28 percent of dairying households maintained herd sizes of 5–10 animals; another 14 percent had herds of 11–50 animals). Only 7 percent of the dairying farms in the country could be considered large, with more than 50 animals (Zia, 2010). In the past 10 years, dairy production and the number of milk producing animals show a trend of continuous increase. According to the FAOSTAT data, the number of milk producing cows and buffaloes in 2012 was 22 and 17 percent, respectively, higher that in 2006, (Figure 13).

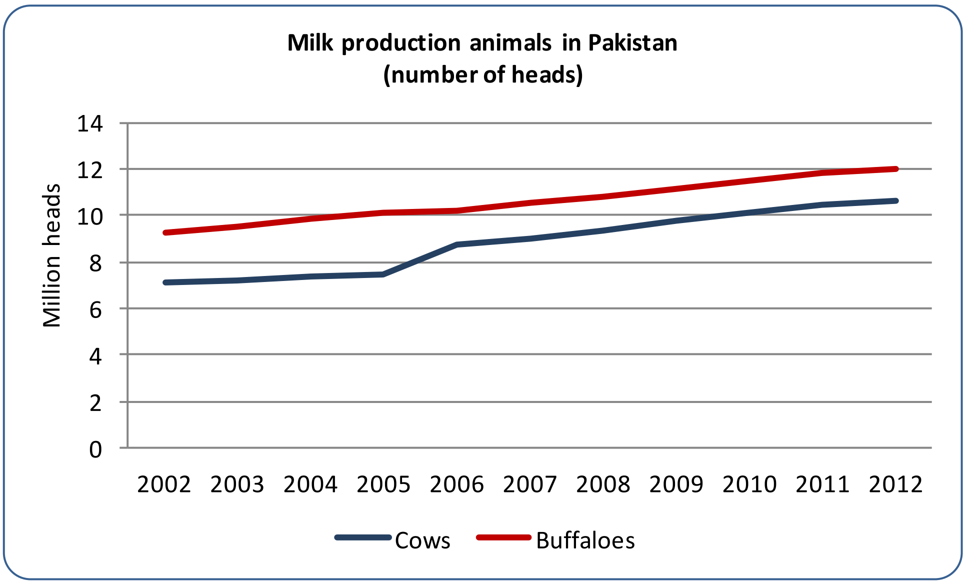

Figure 13: Number of milk production animals in Pakistan in the period 2002-2012 (Source: FAOSTAT, 2014)

Large-scale dairy producers often buy pregnant animals and keep them only for one lactation period, after which they are usually sold for slaughter. There is also a practice of gathering dairy animals to one location, during their lactation period. These are called “cattle colonies”. The "Landhi Cattle

Colony", located in the vicinity of Karachi, is the world's biggest concentration of buffaloes/cattle at one place. In this colony and its vicinity, more than 250,000 buffaloes and cattle are kept together for milk production (Younas and Yaqoob, 200?).

By applying the methodology described in the previous chapter, *Formulae (4) to (9)*, the results of the assessment should show the biogas production potential from household and commercial cattle production for the three species. If the national/provincial values for the amount of manure produced per animal, the percentage of volatile solids and the potential for methane production are not available, global values can be used. Values provided applicable to the Indian sub-continent are given in Table 13.

Poultry manure

Based on the Livestock census in 2006, 64 percent of households in Pakistan owned 1 to 10 birds, 28 percent owned 11 to 25 birds and only 7 percent of households had between 26 and 50 birds. In other words, there were 99 percent of households in Pakistan which owned less than 50 birds. The amount of manure produced by 50 birds has negligible potential for electricity production. Therefore, we recommend considering only the manure originating from commercial producers. The producers can be categorized according to the number of animals kept on average throughout the year. The Census from 2006 distinguishes the following categories: 51-75, 76-100, 101-200, 201-500, 500-1000 birds and more than 1001 birds.

The manure available for biogas production and its energy potential are calculated using *Formulae (10)* and *(11).* If national/province specific values for relevant parameters[5] are not available, global values can be used. Values provided applicable to the Indian sub-continent are given in Table 13.

Table 13: IPCC regional Bo and VS values for cattle and poultry – Indian Subcontinent (Source: IPCC, 2006)

Species	Mass (kg)	Bo m^3 CH_4/kg of *VS*	VS (kg/hd/day)
Buffalo	295.00	0.10	3.10
Dairy cow	275	0.13	2.6
Chicken		0.24	0.02
Turkey		0.24	0.02

4.3.2 Mapping steps, data requirements and data sources

In line with the approach proposed for crop residues, we recommend producing layers for each animal species. For cattle, the potential arising from animals kept by households and those in commercial production should be clearly indicated. The overall energy potential per the minimal spatial unit should be presented in a separate layer.

If maps are produced in raster format and the information about the number of cattle kept by households is available only for the areas larger than the minimal spatial mapping unit, potential may

5 Amount of manure produced per animal, percentage of volatile solids and the potential for methane production.

be averaged within the area for which the data are obtained. This area,though, should not be larger than a district.

In the case of commercial production, it would be optimal to allocate the potential to the location of the production facility, especially for larger producers. The potential arising from small-scale producers can be mapped in the same way as the “household layer”.

Table 14: Datasets and possible sources for mapping availability of livestock manure

Dataset needed	Source of data
Animals kept in(head/LU/TLU): - Household production - Commercial production	Livestock census 2006 (Pakistan Bureau of Statistics) Provincial or national agriculture statistics, technical officers in the departments.
Number of animals in Stable only, Daily grazing, Seasonal grazing feeding system	Field surveys, technical consultations and interviews with agronomists affiliated with the universities, research institutes and agriculture departments of provincial governments.
Amount of manure produced per animal daily (head/LU/TLU)	
Percentage of volatile solids in manure	Laboratory testing. Literature, interviews with agronomist affiliated with the universities, research institutes and agriculture. Global values.
Methane production potential of the manure (species specific)	
Data should be collected for: cows, buffaloes and chicken. Data can further be refined according to the sex and age of the animals.	

4.4 Forest harvesting residues and wood processing residues

According to the FRA2010 (Global Forest Resources Assessment) over the past three decades Pakistan is facing continuous decline in forest cover. In the period from 1990 until 2010 the total forest area declined from 2,527,000 to 1,687,000 ha, with an average annual rate of decline of 1.66 percent.

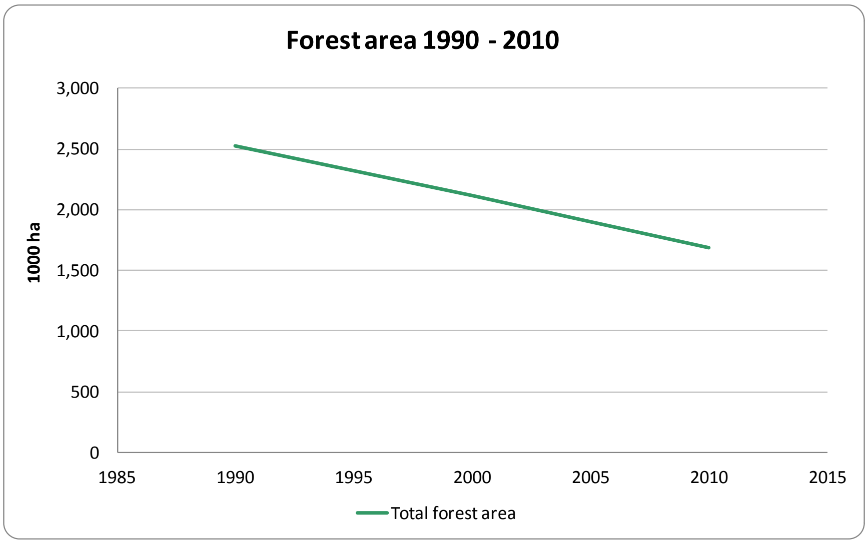

Figure 14: Graphical presentation of the forest cover in the period 1990 to 2010 in Pakistan (Source: FRA2010)

The Global Forest Resource Assessment is conducted on a five-year basis by UN FAO in collaboration with its Member States. In principle, the assessment is conducted using data and information provided by the designated governmental bodies of the Member states. In the case of the FRA 2010 Country Report for Pakistan (FAO, 2010), it is stated that "no report has been received from Pakistan" and that the FRA Report "is the result of a desk study prepared by the FRA secretariat in Rome, which summarizes existing available information using the established format for FRA 2010 country reports".

The Agricultural Statistics from 2010-11, published by the Government of Pakistan reported that the total forest area under the control of the Forest Departments amounted to 11,032,000 hectares, whereby 5,909,000 ha are rangelands and additional 1,584,000 ha are scrub, (Table 15).

Even when comparing data on the area of coniferous forest published by the Bureau of Statistics of Pakistan with the data on total forest cover published in FRA2010, there is a discrepancy of 300,000 hectares for the year 2010. This leads to the conclusion that, either the forest cover reported in FRA2010 is underestimated or that that respective information included in the national statistics is overestimated.

The most recent information on forest area is available from the "*Land Cover Atlas of Pakistan: Sindh Province and Punjab Province"*, which was prepared through the collaboration of SUPARCO and FAO, and published by FAO in 2014. According to the Land Cover Atlases for Sindh and Pubjab, the category *Forests – Trees and Mangroves* covered 115,483 ha in Sindh and 326,349 ha in Punjab. Considering that the majority of forests in Pakistan are located in Balochistan, KPK and Kashmir, this information does not provide any clarification for the above stated discrepancies.

Table 15: Forest area under the control of forest Departments by vegetation types

Category	Punjab	KPK	Balochistan	Glgit Baltistan	Azad Kashmir	Total
	'000 ha					
Coniferous	49	-	1,073	285	408	1,946
Irrigated Plantation	150	90	-	8	-	254
Riverine	55	216	-	-	-	273
Scrub	260	1	64	652	9	1,584
Coastal	-	280	-	-	-	496
Linear Plantation	17	-	2	1	-	21
Range Lands	2,671	458	155	2104	150	5909
Mazri	-	-	24	-	-	24
Miscellaneous	-	-	525	-	-	525
Total	**3,202**	**1,045**	**1,843**	**3,050**	**567**	**11,032**

The available data on the annual forest harvesting, i.e. industrial roundwood production and woodfuel production also differs among different sources. The following figure, Figure 15, shows a graphical comparison of the data published by the Pakistan Bureau of Statistics (2014) and FAOSTAT (2014). It is to be noted that the volume of the annual wood removals is presented in logarithmic scale. The respective numerical values can be found in Table 16.

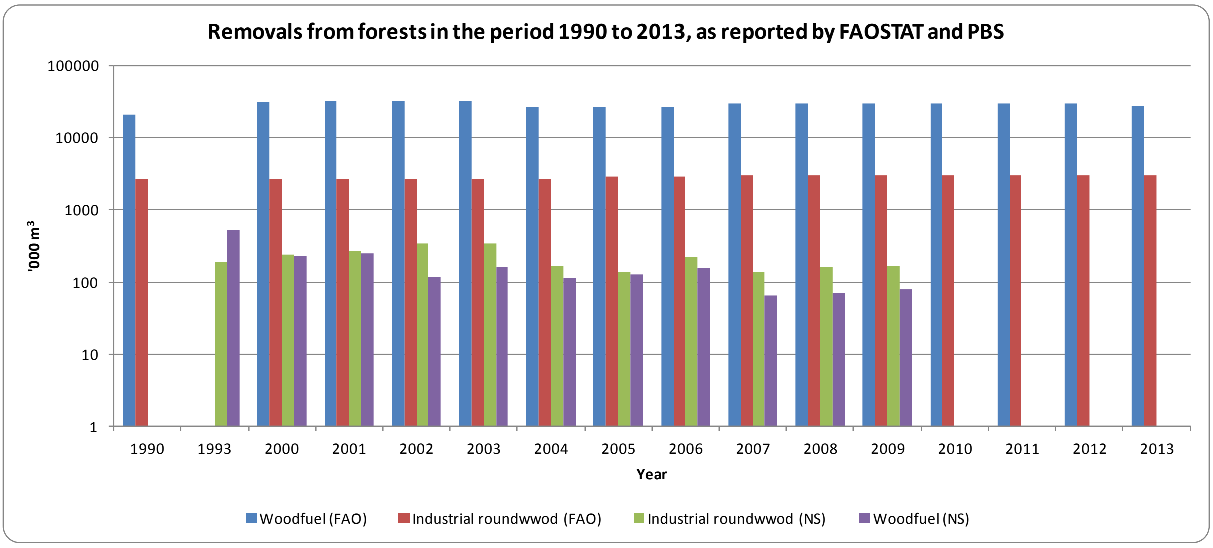

Figure 15: Graphical presentation of the data on wood removal from forests in the period 1990 to 2013 according to FAOSTAT and PBS

As it can be seen from the figure above and table below, the values reported in the national statistics are around a hundred times smaller than those aggregated by FAO. Namely, FAOSTAT flags that only data for woodfuel production in 2007 and 2008 represent *official data,* while the other reported values are aggregates, which may include official, semi-official or estimated data.

Table 16: Wood removals from forests in the period 1990 to 2013 according to FAOSTAT and PBS

Year	Roundwood* (FAOSTAT†)	Woodfuel** (FAOSTAT)	Industrial roundwood (FAOSTAT)	Roundwood (PBS††)	Woodfuel (PBS)	Industrial roundwood (PBS)
			'000 m^3			
1990	23,661	21,043	2,618	-	-	-
1993	24,188	21,986	2,202	703	516	187
2000	33,560	30,880	2,680	472	229	243
2001	34,194	31,515	2,679	514	247	267
2002	34,914	31,515	2,679	454	115	339
2003	34,194	31,515	2,679	503	163	340
2004	28,680	26,000	2,680	282	113	169
2005	29,320	26,500	2,820	265	126	139
2006	29,370	26,500	2,870	373	156	217
2007	32,481	29,520	2,961	204	65	139
2008	32,650	29,660	2,990	233	70	163
2009	32,650	29,660	2,990	248	78	170
2010	32,650	29,660	2,990	-	-	-
2011	32,650	29,660	2,990	-	-	-
2012	32,650	29,660	2,990	-	-	-
2013	30,606	27,617	2,989	-	-	-

*Roundwood includes all wood removed from forests: industrial roundwood and woodfuel. **Woodfuel includes all wood used for energy production, including wood used for charcoal production and that used as firewood. **†** The values reported in FAOSTAT are *"aggregates", i.e. they may include official, semi-official and estimated data.* †† PBS = Pakistan Bureau of Statistics.

The assessment of harvesting and wood processing residues potentially available for energy production should be based on the roundwood and sawnwood production. The above referenced databases and the other reviewed literature sources (Alternative Energy Solution Providers; GEF-UNIDO, 2010; SECOM, 2012) do not provide reliable information either about the volumes of wood harvested and processed in the country, or about the processing efficiency and level or residues utilization. For example, SECOM (2012) reports that the residues are used by the wood processing industries for pulp and paper production, but does not give any further information about the average annual volumes. Due to this, it is not possible to estimate whether there might be any available residues.

However, we recommend to start with a comprehensive collection and validation of data, which will give a baseline for the assessment of existing forest stocks, manner and amounts of material and energy use of wood and the availability for electricity production. The following data should be included in the data collection:

- the existing forest stocks in the country;
- volumes of wood harvested from public and private forests and trees outside forests;
- volumes of wood used for energy and their inclusion into energy balances;
- efficiency of wood processing industries;
- percentage of wood residues currently used.

5 BIOENERGY POLICY DEVELOPMENT

5.1 FAO's Bioenergy and Food Security Approach

There has been growing interest in bioenergy due to potential climate change, energy security, and rural development benefits. At the same time, concerns regarding the potential adverse impacts of bioenergy on food security, the environment and small landholders have also increased. Growing demand for food, population pressure on land use and the growing impacts of climate change will create additional challenges for land and resource management. There is a need to address how bioenergy can be produced in combination with food and other products to enhance both food and energy security.

To date, the rush to promote bioenergy as an alternative to fossil fuels has often occurred in the absence of a full understanding of the costs and benefits associated with bioenergy development and how to target interventions to safeguard and benefit the most vulnerable. Therefore, an integrated approach that assists stakeholders in understanding the various interrelationships of bioenergy and food security is required. FAO developed the ***Bioenergy and Food Security (BEFS) Approach*** to provide guidance on the design and implementation of sustainable bioenergy policies and strategies at both the national and project level. The overall objective of the BEFS Approach is to ensure that bioenergy development fosters food and energy security, and that it contributes to agricultural and rural development in a climate-smart way.

Building institutionalized dialogue

Bioenergy is a cross-cutting issue which requires coordination among diverse stakeholders who often don't have experience in working together (e.g. Ministry of Energy and Ministry of Agriculture). It is particularly important that both agricultural and energy interests are incorporated in addressing bioenergy development so that the full implications of the production chain are considered in determining both public and private sector interventions.

At the national level, the BEFS Approach stresses inter-ministerial collaboration through the creation of working groups to define the country specific issues and priorities in addressing bioenergy and food security with the private sector and civil society. Thereby, initially the governmental institutions will have the lead in policy development. The table below includes a summary of the types of actors that should be consulted and included in bioenergy policy-making and project decisions, through the establishment of multi-stakeholder working groups and/or coordination mechanisms.

Table 17: Stakeholders relevant for bioenergy policy and project development

Government	Private Sector	Civil Society
Energy	Feedstock Producers	Land Rights Organizations
Agriculture, Livestock, Forestry	Feedstock Processors	Community Based Organizations/Groups
Food Security	Import/Export Agencies	Farmer Organizations
Rural Development	Fertilizer Producers/Sales	Labour Organizations
Land Planning, Environment	Energy Suppliers	Trade Organizations
Water Resources	Financial Institutions	Environmental Organizations
Investment	Research Institutions	Fair Trade Organizations
Trade	Consulting/Advisory Firms	Community members/public
Finance	Fuel transportation	Development Agencies

Scoping and assessment of the sustainable bioenergy potential

Given that the BEFS Approach is country and context specific, it is important to begin with an initial step to define the scope of how the BEFS Approach will be implemented in each case. The scope should be defined in close collaboration with key stakeholders from diverse sectors and backgrounds. The overall objective of this step is to define the work plan of the working group for answering the key question of how bioenergy can contribute to overall development objectives while fostering food security. The overall questions usually addressed are:

1. How can bioenergy contribute to overall development objectives, while fostering food security?
2. What are the main issues and drivers for pursuing bioenergy?
3. What are the potential and feasible bioenergy production options?
4. Are there any, and/or what are food security implications?
5. What are the policy interventions to foster sustainable bioenergy development?
6. What are the risks and opportunities arising from bioenergy development?
7. What can other stakeholders (private sector, communities, etc.) do to foster sustainable bioenergy development?

The assessment of sustainable biomass potential for energy production, technical and financial viability of its conversion into final energy forms and the potential socio-economic effects on the project, community and national level are baseline factors for policy decision-making. The BEFS Approach includes two levels of assessment to facilitate understanding and comparison of the trade-offs of various options. One that is faster but less detailed, the BEFS Rapid Appraisal, and one that involves a more detailed analysis based on the conceptual foundation of the BEFS Analytical Framework. The methodology for biomass resources assessment described in Chapter 3 of this document is applied in both BEFS Rapid Appraisal and BEFS Analytical Framework.

The results of the assessment provide country specific evidence, taking into account characteristics of the agricultural production, food security and energy demand of the country. Country capacity for deployment of different technologies can also be taken into account. This evidence is then used to support the inter-ministerial dialogue and definition of the bioenergy policy that will ensure sustainable and efficient use of natural resource and serve the needs of the country (e.g. energy supply, job creation, rural development, improved agricultural production, etc.).

Sustainable bioenergy policy formulation

In order to target policy interventions to ensure that bioenergy contributes to overall development objectives, a review of the existing policy and legislative framework is first required. This process allows for the identification of gaps in current policies, while taking into consideration the results of the BEFS Scoping and Assessment (if conducted) which have indicated key risks and opportunities. The analysis of relevant legislation in view of the national priorities for bioenergy and the elements of a bioenergy policy, is to determine whether (and the extent to which) the existing legislation is conducive to bioenergy and food security priorities and policy.

Throughout the policy formation, it is necessary to prevent risks to the maximum possible extent and also foresee measures for preventing and management of risks that might arising during the policy implementation. Thereby, impact monitoring evaluation and response play an important role. The BEFS Approach includes indicators for monitoring the impacts of bioenergy development in collaboration with the Global Bioenergy Partnership. In order to assess impacts of bioenergy development, it is first necessary to collect baseline data along the key indicators for the specific country context; then to analyse and evaluate the data collected along each indicator to determine relevant and targeted policy responses.

5.2 Governmental bodies relevant for bioenergy sector development in Pakistan

Pakistan is a federal parliamentary republic consisting of four provinces: Punjab, Sindh, Khyber Pakhtunkhwa (KPK) and Balochistan, and four federal territories: Islamabad Capital Territory, Federally Administrated Tribal Areas (FATA), Gilgit Baltistan of Pakistan (formerly known as the Northern Areas) and State of Azad Jammu and Kashmir.

The Federal government is composed of three main branches: executive, legislative and judicial. The President, Prime Minister and the National Security Council represent the executive government, while the legislative composes of the parliament, senate, national assembly, federal government ministries and federal ministers. The role of 28 Federal Government Ministries and their divisions is mainly strategic planning and policy-making at the country level. They are also facilitating sectoral inter-provincial coordination and international cooperation, (Government of Pakistan, 2014).

The Federal government includes 28 ministries of which five are relevant for the development of the bioenergy sector. The Ministry of Water and Power and the Ministry of National Food Security and Research will have the most important role for biomass resource assessment and in bioenergy policy-making: setting strategic targets and developing respective policies at the federal level, as well as mainstreaming implementation of programs and projects at all levels (federal, provincial and local). For an industry to develop and sustain, along with the policy and legal framework, it is important to create supporting technological, infrastructural and knowledge capacity in the country. For this the Ministry of Industries and Production, and the Ministry of Science and Technology will play a role.

Based on the analysis of their official mandates, a number of bodies (e.g. boards, institutes, agencies or departments) attached to the abovementioned ministries have been identified as relevant for biomass assessment and mapping, and the development of the bioenergy sector. The following tables give an overview of the respective bodies, their current mandates and relevance for bioenergy development. A list of all Federal ministries and their divisions, with links to their official web site, can be found in the Annex.

Table 18: Ministry of Water and Power – bodies relevant to bioenergy

MINISTRY OF WATER AND POWER	
Ministerial body	**Alternative Energy Development Board**
Mandate	Development of national strategy, policies and plans for utilization of alternative and renewable energy resources to achieve the targets approved by the Federal Government in consultation with the Board. To act as a forum for evaluating, monitoring and certification of alternative or renewable energy projects and products. To facilitate power generation through alternative or renewable energy resources.

Relevance for bioenergy sector development	Support to the development of sustainable and food secure bioenergy policy by facilitation of inter-ministerial (inter-sectoral) cooperation and decision making. Ensuring that bioenergy projects, i.e. investments, correspond to the existing biomass potentials of the area of project implementation andare in line with bioenergy, food security and other relevant policies, e.g. agriculture and rural development, etc.

Table 19: Ministry of National Food Security and Research – bodies relevant to bioenergy

THE MINISTRY OF NATIONAL FOOD SECURITY AND RESEARCH (MNSFR)	
Ministerial body	**Agricultural Policy Institute**
Mandate	Conducting of studies on emerging policy issues, analysis of the impact of agricultural policies and recommendation of policies and programs to increase the efficiency and improve the competitiveness of agricultural commodities.
Relevance for bioenergy sector	Support to long-, medium- and short-term bioenergy policy-making and planning. For example, the existing expertise and country specific knowledge can be utilized for conducting an analysis on the implications of the use of agricultural commodities, residues and waste for energy production, and for providing recommendations on how to use bioenergy as a means to improve agricultural competitiveness, as well as on which safety measures to impose in order to avoid negative impacts of bioenergy on food security, agricultural production, environment, etc.
Institution	**Economic Wing**
Mandate	Collection, compilation and dissemination of agricultural statistics at national and international level. Collection of crop area, production and other agricultural statistics from Federal and provincial Governments, FBS and other department/agencies. The crops include cereals, pulses, oilseeds, fruit vegetables and condiments.
Relevance for bioenergy sector	Support to long-, medium- and short-term bioenergy policy-making and planning at the national level. Data on agricultural production, crop types, production quantities and areas, collected and analyzed in a systematic manner over long periods provide the key information for assessing the biomass production potential and spatial analysis (biomass mapping).
Ministerial body	**Pakistan Agricultural Storage & Services Corporation (PASSCO)**
Mandate	Ensuring national food security by maintaining strategic reserves of different food grain commodities which are provided to food-deficit provinces. Implementation of support price policy to stabilize prices. Carrying out agro-business activities with national and international organizations that help farmers achieve self-sufficiency and sustainability in food grain commodities.
Relevance for bioenergy sector	Support in bioenergy planning and implementation of bioenergy projects by ensuring that they contribute to national food security or, at least, do not impose any negative effects on it.
Ministerial body	**Pakistan Agricultural Research Council**

Mandate	Conducting, promoting and coordination of agricultural research by establishing research establishments to fill in research gaps, ensuring the expeditious utilization of research results, arranging the training of high level scientific manpower, generating, acquiring and disseminating information and establishing and maintaining a reference and research library.
Relevance for bioenergy sector	Through inclusion of the bioenergy topics as part of its activities, the Research council can provide research and scientific support for evidence based decision making at all levels (policy, planning, implementation of projects), dissemination of information and awareness raising about bioenergy.
Ministerial body	**Pakistan Oilseed Development Board**
Mandate	Conduct research in collaboration with Provincial Governments, provide coordination and policy formulation, support, design and implement projects, collect, compile and maintain statistics in the oilseed sector.
Relevance for bioenergy sector	Oilseeds are used for the production of straight vegetable oil (SVO) and biodiesel. The existing knowledge capacity of the Board can be of high value to provide recommendations on the most appropriate oilseed varieties and to provide expertise to oilseeds producers and project developers targeting the bioenergy sector. Statistics on the oilseed sector form part of the key baseline information for the development of SVO and biodiesel production facilities and planning of their production.
Ministerial body	**Livestock and Dairy Development Board**
Mandate	Planning, promotion, facilitation and coordination of livestock, poultry and dairy sectors development. Promotion and facilitation of marketing of livestock and livestock products. Promotion and facilitation of producer-owned and controlled organizations. Capacity building of all stakeholders. Promotion and dissemination of improved technologies.
Relevance for bioenergy sector	Manure management is one of the most important environmental concerns of the livestock production. At the same time, manure is a valuable resource for biogas production, which can consequently be converted into energy (electricity and heat) and nutrient rich fertilizer (digestate). Utilization of manure for biogas production is a compatible activity for livestock producers, which brings added value by both ensuring additional income though the self-supply or sale of energy and fertilizers, and though diminishing costs of manure disposal. The Board may play an important role in the promotion of biogas production and building capacity of all stakeholders.
Ministerial body	**Pakistan Dairy Development Company**
Mandate	To increase access to quality dairy products, develop training systems for the dairy sector, introduce improved Dairy Foods standards and regulation, and improve and increase Animal Health services.
Relevance for bioenergy sector	Support to implementation of biogas projects in dairy sector, in line with the activities of, and in cooperation with, the Livestock and Dairy Development Board. Support and provision of information on the use of crop residues as feed to the policy-makers and project developers engaged in the utilization of crop residues as bioenergy resource.

Ministerial body	**Fisheries Development Board**
Mandate	Coordination of national and provincial activities with relation to aquaculture and shrimp farming. Promotion of joint ventures between foreign and local investors in the field. Preparation and implementation of plans according to regional specific requirements. Development of market infrastructure and improvement of marketing of fisheries products.
Relevance for bioenergy sector	Residues and waste from aquaculture can be used as a feedstock for biogas production. The Fisheries Development board may play the same role in this sector as the Livestock and Dairy Development Board in the Livestock sector.

Table 20: Ministry of Industries and Production, Ministry of Science and Technology, Cabinet Secretariat Ministry: relevance to bioenergy

MINISTRY OF INDUSTRIES AND PRODUCTION	
Mandate	Acts as a policy formulating agency and a focal point for promotion and expansion of industrial sector of the country.
Relevance for bioenergy sector	Promotion of bioenergy technologies and supporting industries in the country.
MINISTRY OF SCIENCE AND TECHNOLOGY	
Mandate	Planning, coordinating and directing efforts to initiate and launch sound and sustainable scientific and technological programs and projects. Involved in various areas of industrial development including renewable energy and rural development.
Relevance for bioenergy sector	Promotion and support of research and development of bioenergy technologies in the country.
CABINET SECRETARIAT MINISTRY	
Ministerial body	**Climate Change Division**
Mandate	Responsible for ensuring that climate change is mainstreamed economically and socially in the various sectors of the country: energy, water, forestry, agriculture and livestock. Ensuring that coastal areas, biodiversity and other vulnerable ecosystems incorporate climate resilient development.
Relevance for bioenergy sector	Promotion and awareness raising about bioenergy as a means to mitigate climate change and reduce GHG emissions from the energy sector.

6 AN OVERVIEW OF RELEVANT RESEARCH AND PREVIOUS/EXISTING ACTIVITIES

Pakistan has been facing huge energy crises throughout the last decade. The demand and supply gap is continuously increasing; the demand side is growing on a daily basis, whereas the supply side has not been able to meet the existing demand. The most critical impact is on the economic growth of the country. The industrial and commercial sectors are exceptionally affected by this energy deficit, resulting in declining growth and shutting down of various small, medium and large industries. An additional problem is that current energy supplies are not available to all parts of the country. This especially refers to rural areas, where almost 40 percent of the total population reside.

The Government of Pakistan has been endeavouring to exploit various options to meet with current and future anticipated energy needs of the country. Conventional energy supplies have been the focus of the overall energy planning framed with the National Power Policy 2013, which foresees large hydro power projects and conventional thermal power projects. The substantial potential of the renewable sources within the country has also been acknowledged. Thus, the Government has established the Alternative Bioenergy Development Board within the Ministry of Water and Power and endorsed the Medium Term Policy for Development of Alternative and Renewable Energy. The current policy was enforced in March 2011, superseding the Short Term Policy from 2006. Under the umbrella of this Short Term Policy, a Framework for Power Cogeneration from Bagasse and Biomass was endorsed in March 2013.

Apart from these policy documents, the licensing procedure for the development of renewable energy projects is functional and there are a number of projects in the pipe-line. As of September 2014, a Generation Licence was granted by the National Electric Power Regulatory Authority to nice bioenergy facilities with a total planned installed capacity of 226.75 MW. Seven of the bioenergy power plants plan to use bagasse as fuel, whereas a combination of bagasse and rice husk, and cotton stalk and woodchips are foreseen fuels for the other two facilities. The list of facilities which were granted a generation licence prior to October 2014, with basic information on the installed capacity, primary and secondary fuels and expected lifetime is included in Annex III.

International development organisations are also active in the field with several ongoing programmes and projects. The most relevant to single out are the GEF-UNIDO project *"Promoting sustainable energy production and use from biomass in Pakistan"* and the GIZ project *"Development of market based approach for utilization of biomass in industrial power generation"*. As part of the GER-UNIDO project, a Pre-feasibility study for the use of gasification technology in selected industries and for rural electrification was prepared, while within the GIZ project a report on biomass potential assessment and feedstock preparation was published. A short overview of the objective, content and relevance of these documents for biomass resource assessment and mapping is given in the following subsections.

Other relevant documents, studies and reports that do not directly address bioenergy, do address sectors directly related to agricultural production and/or refer to the use of biomass resources.

Each of the documents discussed above are shortly described in the following sub-sections. The description includes the objective of the study, content and relevance for biomass resource assessment and mapping. A list of national and provincial statistical data available for download is also included.

6.1 Policy documents

6.1.1 National Power Policy 2013

Goal and Objective:

This document frames the broad contours of the energy policy and defines the following vision for the power sector: *"Pakistan will develop the most efficient and consumer centric power generation, transmission, and distribution system that meets the needs of its population and boosts its economy in a sustainable and affordable manner."*

This document does not elaborate on issues surrounding the operational strategy, nor does it lay out detailed implementation plans. It provides a guidance and framework for the development of the power sector, highlighting its key challenges, setting major goals, summarizing policy principles, and highlighting the strategy devised to achieve Pakistan's aspirations.

Short Summary of the Content:

The Policy encompasses nine chapters. The introduction, vision, challenges, goals and targets are described in the first five chapters. Arising from the challenges Pakistan is facing, the goals and targets emphasize the need for an increase in efficiency and a decrease in the cost of electricity production, a reduction of transmission and distribution losses as well as theft, and a higher collection of payments. The establishment of new energy production facilities and the construction of an energy infrastructure will have an important role in the development of this sector. Chapters 6 and 7 define the policy principle and strategies for each component of the energy sector: production, transmission, distribution, governance, in line with the defined targets. Finally, the last two chapters, Chapter 8 and 9 are devoted to the prioritization and impact of the Policy.

Relevance for biomass resource assessment and mapping in Pakistan:

The National Power Policy 2013 focuses primary on conventional energy sources, whereas renewable energies are mentioned only as a potential additional source for meeting the energy demands.

The policy has no direct relevance for biomass resource assessment and mapping. However, it provides a framework for the implementation of the Medium Term Policy for Development of Alternative and Renewable Energy, which is the key policy document for bioenergy sector development.

6.1.2 Medium Term Policy for Development of Alternative and Renewable energy (2011)

Goal and Objective:

In 2011, the Alternative and Renewable (ARE) Energy Policy (2006) was updated by the Medium Term Policy. The goal of the policy is to harmonise ARE-related efforts of various Government bodies and foster the development of the sector addressing all relevant aspects, from technology deployment to capacity building and research and development.

Short Summary of the Content:

The ARE Policy 2011 builds on the Medium Term Policy from 2006 by further defining its objectives:

- Resolving policy conflicts and addressing stakeholder concerns;
- Developing the concept that ARE projects actually cost the nation less and thus deserve and require a better rate of return than fossil fuels;
- Developing the policy of non-electric RE and a policy for Biofuels;

- Expanding incentives for ARE such as: the Alternative Energy Development Fund, partial resource risk coverage, tariffs on the basis of a premium rate of return for developers, mandatory grid connection, mandatory purchase requirements, small business programmes for ARE (<10 MW), Asian Development Bank (ADB) loan guarantee facility, credit market facility and 100% carbon credits to Independent Power Producers.

The Medium Term Policy from 2006 is a comprehensive document addressing energy sector institutions and their roles, strategic objectives, goals and development strategy for ARE. Furthermore, targets and financing issues as well as procedures for project development are defined and elaborated. Complementary parts of the document are the *On-grid ARE source Electricity Policy, Rural Energy Services Policy and Biofuels Policy.*

Biogas, biomass (including, but not limited to, bagasse, crop residues, fuel crops and wood) and biofuels (including ethanol and biodiesel) are defined as alternative energy, while renewable energy systems include geothermal, hydro, solar, tidal, wave and wind energy.

Relevance for biomass resource assessment and mapping in Pakistan:

The Medium Term Policy is the main policy document regulating the use of renewable energy sources. As such, this document provides a policy framework and motive to conduct biomass assessment and mapping which will support its implementation.

6.1.3 Framework for Power Cogeneration 2013 (Bagasse / Biomass)

Goal and Objective:

The Economic Coordination Committee (ECC) of the Cabinet, in its meeting held on 6 March 2013, approved the *"Framework for Power Cogeneration 2013 Bagasse and Biomass"* as an addendum to the Renewable Energy Policy. This framework is effective for all high-pressure cogeneration projects utilising bagasse and biomass.

Short Summary of the Content:

The power producer may establish the project as part of an existing sugar mill or as a separate entity. The upfront tariff for bagasse/biomass-based cogeneration projects is determined by the National Electric Power Regulatory Authority (NEPRA). Power producers can offer electricity to the respective distribution companies (DISCOs) or to the Central Power Purchase Agency (CPPA) provided that the cost of interconnection, grid station upgrades, etc. shall be incurred by the respective DISCOs. It shall be mandatory for the power purchaser to consume all the energy offered by the power producer.

There shall be no requirement for feasibility or firm costs from the power producers. However, they will be required to submit grid interconnection studies and initial environmental examination reports to relevant agencies/departments.

Relevance for biomass resource assessment and mapping in Pakistan:

The Framework defines favourable conditions for the production of electricity from bagasse and biomass. Positive effects can already be seen by the number of Generation Licences issued for bagasse utilisation. Biomass assessment and mapping will supplement this Framework with the evidence on the geographical distribution of the biomass available for bioenergy production.

6.2 Reports from projects implemented by international organisations

6.2.1 Biomass Potential Resource Assessment & Feedstock Preparation Report

This report was prepared as part of the Project "*Development of market based approach for utilization of biomass in industrial power generation"*, which is implemented by the GIZ Renewable Energy and Energy Efficiency Programme*.* The report was prepared by a consultancy company, Alternative Energy Solution Providers, in 2012 (2013).

Goal and Objective:
The goal of this Report was to evaluate and demonstrate the availability of agricultural residues for energy generation in industries in eight regions of the Punjab province: Faisalabad, Chiniot, Jhang, Nankana Sahib, Okara, Sahiwal and Burewala. More specifically, the focus is on the potential application for electricity generation and cogeneration of electricity and heat.

The Objectives of the Report were to:

- identify the kind and quantity of biomass generated in the region;
- determine the current consumption and net availability of biomass, as well as when and where the biomass is available;
- specify the pre-conditioning requirements for the biomass and estimate the costs of most appropriate methods

Short Summary of the Content:

The report includes 15 chapters, which can be grouped into:

- chapters about biomass as a renewable energy source and biomass categorization (Chapters 2 and 3);
- description of the methodology applied in field surveys, the characteristics of the survey areas and identified biomass sources available in the targeted regions (Chapters 4-7);
- assessment results on current consumption of crop and woody residues and availability for energy production in industries (Chapters 8-10);
- characteristics of the most suitable residues (Chapters 11-13);
- description of the methods and mechanization for biomass collection, transportation and storage and related costs for the most appropriate methods (Chapters 14 and 15).

Relevance for biomass resource assessment and mapping in Pakistan:

The report gives a good overview of residues generation and patterns of their use in the assessed areas. The most abundant crop residue types suitable for electricity production are identified and the potentially available amounts evaluated.

The assessment of the crop residues availability is based on the data retrieved through field surveys and interviews with farmers, on the one hand, and statistical data obtained from the Agricultural Department of Punjab, on the other. The information about attained yields, residue-to-crop ratio, current uses of residues and farm-gate prices obtained if sold was collected through the field surveys. The average information about the crop yields from the surveys was compared with the statistical data and the differences commented. The total production of crops and crop residues in the assessed areas was calculated using information about the crop yields and residue-to-crop ratio from the surveys and the production area from the statistical data. The differences in the calculated production of crops and the statistical data were observed.

Such an observation could have been expected, due to the fact that the methodology applied and data used for calculation of the total production were different. Namely, in general, the information about the average yields reported in agricultural statistics is calculated based on the production (amount of the crop put on the market) and the harvested area of the respective crop.

The Report also includes valuable information about crop residues identified as the most suitable bioenergy feedstock. For each crop residue type, there is information about the production of the respective crop, seasonality of residues generation, current uses and farm-gate/market price of the residue type.

The final chapters of the Report (14 and 15) give an approximation of the accessibility of the crop residues and provide an estimation of costs related to the logistics. This information can be a valuable guidance for biomass resource assessment and mapping and to develop a more detailed analysis.

In the case of residues arising from the wood processing industries, the Report indicates that there are very limited or no amounts potentially available for electricity generation. To be exact, these residues are already being used either by the wood processing industries or by paper and cardboard manufacturers. It is also important to note that the authors had somewhat limited access to the relevant data, due to difficulties in communication with the sectorial associations and unwillingness of the industries' representatives to share the information.

Other literature sources and reports also indicate a limited availability of woody residues. Nevertheless, when conducting a biomass resource assessment and mapping, we recommend to map the amounts generated as well as those currently used. Further information about the efficiency of energy conversion may indicate potential improvements in efficiency of the resource use, and consequently its availability.

Comments and Recommendations:

The structure and writing of the Report make it somewhat difficult to follow and grasp the results. Nevertheless, the approach and methodology applied are technically sound and the information gathered through the surveys and the results on residues availability can provide a good guidance for biomass resource assessment and mapping.

Considering that the area of assessment was limited to a few regions of Punjab province, we recommend validation of the parameters (residue-to-crop ratio, production of the crops) and application of the same approach and methodology in the other parts of Pakistan.

6.2.2 Pre-feasibility Study: Promoting sustainable energy production and use from biomass in Pakistan to meet Energy Needs of SMEs and Rural Electrification

This Pre-feasibility Study was produced in the framework of the GEF-UNIDO project "*Promoting sustainable energy production and use from biomass in Pakistan"*.

Goal and Objective:

The objective of this UNIDO Industrial Energy Efficiency (IEE) project is *"To promote market based adoption of modern biomass energy conversion technologies for power and process heat generation in SMEs in clusters and power generation in rural areas in Pakistan"*. This Pre-feasibility study described here is a component of the named project.

The objective of the study was to define a path for the implementation of gasification technologies in a manner to benefit Pakistan's economy. During the project preparation phase (PPG), a selection of possible demo projects for the application of gasifier technology development and promotion in Pakistan was conducted. Potential SMEs and locations were screened against a set of criteria to ensure the feasibility and potential of scale-up. The criteria included the interest and willingness of entrepreneurs interviewed, availability of biomass feedstock, economic feasibility and other benefits (social, environmental).

Among the SMEs 3-4 demo industrial units were selected in Punjab for logistical reasons, while for rural electrification a remote village in Sindh was selected, with the following applications:

- SMEs that have high requirements for process heat (such as ceramics firms, brick kilns);
- Power generation (augmenting or replacing power from the grid and generators) and heat supply in individual SMEs that produce excess biomass (e.g. rice mills, wood processing factories);
- Rural electrification, i.e. providing power to villages that are not connected to the power grid, and grid-interfaced applications where the proximity to the power grid allows for feeding of excess power into the grid and augmenting grid power in case of power outages.

Short Summary of the Content:

The Pre-feasibility study is divided into four sections:

- Section 1 gives an overview of the biomass conversion technologies and biomass gasification for power and heat generation, international experience of biomass gasification and human resource requirements to operate and maintain biomass gasification power plants;
- Section 2 gives an overview of biomass resource data of the country, estimation of power and heat generation and assumptions made therein to calculate the figures;
- Section 3 elaborates the technical and financial parameters for SMEs;
- Section 4 describes the village electrification part.

Relevance for biomass resource assessment and mapping in Pakistan:

Section 1 of the Pre-feasibility study includes four chapters (Chapter 2 to 5) on combustion and gasification CHP technologies. Apart from a detailed description of the technology characteristics, this section includes information about biomass characteristics related to gasification and different types of fuels, factors affecting gasification, as well as application of the technologies for heat and power generation. Two chapters are devoted to the power generation economics and suitability of technology, which provide guidance on how to assess potential projects. Chapter 4 includes case studies on the application of the gasification in four countries as well as a list with contact details of international manufacturers of biomass energy systems. Finally, Chapter 5 gives an overview of the human resources required for installation, operation and maintenance of biomass gasification power plants.

This Section of the report is not directly relevant for the biomass resource assessment and mapping, but understanding of the biomass conversion technologies, their technical characteristics and logistic and economic requirements, helps defining the assessment approach and methodology, as well as deciding on how to present the results. Namely, project developers (investors in conversion technologies) will be the most important users of the maps.

Section 2 is the most relevant for biomass resource assessment and mapping. The first part of the Section (Chapter 6) gives an overview of the recent performance of crop, livestock and forestry production in the country. Along with statistical data on the production of major and minor crops, reasons for certain trends and changes in production are explained. For example, since 2007-08 shifts from sugarcane to wheat and other crops have been observed, which resulted in lowering the production area and overall production of sugarcane. The reason behind this is due to a decreased water supply and problems with irrigation, high input costs and no payment from the sugar mills.

Cotton, sugarcane, rice and wheat are addressed as major crops, while oilseeds and other crops and vegetables are given less emphasis. The growing livestock, and especially commercial dairy production is also acknowledged here. In the case of forestry, the problems of deforestation and existing policy documents and re-forestation actions are described.

The authors point out the potential of crop and livestock residues as resources for bioenergy. In case of the use of woodfuel, improvement of sustainable forest management and efficient utilisation of residues in wood-processing facilities are suggested as preferred measures.

The second part of the Section defines the assumptions and gives a detail overview of computation of biomass availability, potential for syngas production and its conversion to electricity. The assumptions include residue-to-crop ratio for wheat straw, rise husk, sunflower cob, cotton stalk, maize cob, paddy (rice) straw and sugarcane bagasse. The collection coefficient for agricultural and forestry residues is assumed at 65 percent. The production of manure per head of cattle and buffalo is estimated at 15 kg per day, and the collection rate assumed at 50 percent. The assessment of the availability of biomass was calculated for each of the four provinces and at the national level, based on the production of crops and number of animals as reported in the agricultural and forestry statistics.

Section 3 focuses on what energy issues are being faced by the SMEs, what options they have to meet their energy needs and how the biomass gasification technologies can be beneficial for them on technical, financial and economic grounds. The Section starts with an introduction to the assessed and selected SMEs and adescription of their processes, energy needs and current energy supply. This is followed by a detailed assessment of possible options and technical, environmental and financial assessments of the proposed options.

The final section, Section 4, addresses rural electrification. An overview of the status of electricity supply in rural areas of Pakistan is given, together with a description of options for off-grid and decentralised electrification. The rest of the Section focuses on the feasibility of electrification of a village in Sindh provided with a gasification plant. It includes an assessment of feedstock availability and energy needs and aproposed design of the gasifier, including atechnical and financial feasibility assessment.

Comments and Recommendations:

The Pre-feasibility Study is a well-structured document with a clearly described approach and methodology applied. The content of the Study comprises all relevant aspects of the development of a gasification project in SME and for rural electrification. In addition it provides further information about the technology and its application.

The most relevant parameters for biomass resource assessment and mapping are included in Section 2, which includes an assessment of the availability of crop and woody residues on the national and provincial scale. We recommend applying the same approach, whereas it would be beneficial to validate and update the parameters obtained from literature and national statistics.

6.2.3 Other reports addressing agricultural and forestry sectors

Pakistan: Priority areas for investment in the agricultural sector

This Report was prepared by the FAO Investment Centre under the FAO/World Bank Cooperative Programme in 2012. The Report provides an overview of priority areas for investment in the agricultural sector of Pakistan which include: (i) agricultural research and extension, (ii) the seed sector, (iii) water resources and (iv) rural finance.

The Report discusses the current challenges as part of the identification of the areas for investment. As the production of biomass is directly linked to agricultural production, the existing limitations for the development of agricultural production also have effects on biomass for energy production and thus the bioenergy sector could also benefit from future investments.

Dairy development in Pakistan

The Report was prepared by Umm E. Zia, T. Mahmood and M.R. Ali and published by FAO in 2011. It gives an overview of the existing milk production systems and their impacts on the environment and livelihoods and the safety of milk and dairy production, and provides an analysis of the value chain. Within the Discussions and Conclusions of the Report, the authors provide recommendations and guidelines on how to address the major challenges and contribute to a better livestock management and dairy production in the country. Environmental pollution, insufficient feed production and low quality and/or insufficient infrastructure were identified as some of the major problems of the dairy industry in Pakistan. In addition, the Annexes include statistical data on the livestock population and milk production, production systems and their characteristics, and other data.

The statistical data and characterisation of production systems are relevant for assessment of the generated manure, which can be used for biogas production. Utilization of this manure for energy purposes can also contribute to the improvement of environmental performance of the dairy sector. The information on feed production and feeding characteristics can also provide information relevant for assessment of current use of crop residues, which is one of the parameters relevant for assessment of their availability for energy production.

Pulp and paper industry in Pakistan

This report includes general information about the pulp and paper industry in Pakistan: current status and types of paper produced, which type of raw materials and feedstock are used and their availability. There are also sections on the current status of trade, potential for export and future outlook.

The information about the feedstock used for pulp and paper production, types and amounts are relevant for the assessment of biomass available for energy production. Therefore, it should be taken into consideration in the course of biomass assessment and mapping.

The Report was prepared by SECOM, with the support of the Embassy of Brazil.

6.3 National and provincial statistics

The table below gives an overview of the statistical data publicly available and accessible via Internet.

Table 21: National and provincial statistics readily available and accessible via Internet

Country level / Province level	Content
Crops area and production by districts (1981-82 to 2008-09), Volume I:Food and cash crops	Key food and cash crops, Pakistan, District level statistics
Agriculture Statistics of Balochistan (2009-10)	Key food and cash crops: coverage, production and yield. Livestock: number of heads (projections); slaughtered animals; meat production. Forestry: Forest coverage by type, timber, firewood resin and mazri production.
Agriculture Statistics of Sindh	Livestock slaughtered by district Forestry production for 2006/07, 07/08 by district Crop production (ha) kafir, rabi 07/08
Agricultural statistics for Punjab	Key food and cash crops: coverage, production and yield for 2009/10

7 ANNEXES

7.1 Annex I: Provincial governmental bodies relevant for bioenergy sector

The four provinces have considerable autonomy. Each province has a governor, a Council of Ministers headed by a chief minister, and a provincial assembly. Although there is a well-defined division of responsibilities between federal and provincial governments, there are some functions on which both can make laws and establish departments for their execution. Most of the services in areas such as health, education, agriculture, and transport infrastructure are provided by the provincial governments, while the federal government defines national policies and handles international affairs (Government of Pakistan, 2014).

The departments of provincial governments act as implementing bodies of the government. Number of department and the sectors covered by each, differ among the provinces. Divisinis and districts are third and four administrative levels, respectively. They are administrated by local District Governmental Administrations. Names of divisions and number of districts in Pubjab, Sindh, KPK and Balochistan are given in Table 22.

Table 22: Provinces and divisions of Pakistan

PROVINCE	DIVISIONS		Number of districts
Punjab	Bahawalpur Dera Ghazi Khan Faisalabad Gujranwala Lahore	Multan Rawalpindi Sargodha Sahiwal	36
Sindh	Hyderabad Karachi Larkana	Mirpur Khas Banbhore Sukkur	23
Khyber-Pukhtunkhwa (KPK)	Bannu Dera Ismail Khan Hazara Kohat	Malakand Mardan Peshawar	24
Balochistan	Kalat Makran Naseerabad	Quetta Sibi Zhob	30

7.1.1 Punjab Province

Punjab is the second largest and the most densely populated province of Pakistan. According to the census, in 1998 the total population was 73.6 million (Pakistan Bureau of Statistics, Census 1998). Different sources quote estimates that the population will grow to around 94 million by 2012. Agriculture is the major source of income and employment, whereby wheat, rice and cotton are the principle crops produced. Other crops grown include sugarcane, millet, maize, oilseeds, pulses, fruits, and vegetables. Livestock and poultry production are also an important part of the overall agricultural production. Compared to other provinces, Punjab is one of the most industrialized in the country with a well-developed infrastructure.

The provincial government has 38 departments. The departments relevant for biomass mapping are the Agriculture Department, Livestock and Dairy Development Department and Forestry, Wildlife and

Fisheries Department. The majority of data required can also be provided by the Bureau of Statistics. Along with the listed departments, one of the main stakeholders in the development of the provincial policy and bioenergy sector in general, will also be the Energy Department. A more detailed overview, with descriptions of the departments, their mandates and relevance for biomass mapping and development of bioenergy sector is given in the following tables. A list of all Provincial departments, with links to their official web site, can be found in the Annex II.

Table 23: Punjab Province Departments relevant to bioenergy

AGRICULTURE DEPARTMENT (AGRI PUNJAB)	
Mandate	Responsible for making agriculture cost-effective and knowledge based, ensuring food security, poverty reduction, removing regional disparities, generating trade surplus, connecting farmers to markets and diversifying crops to ensure sustainable growth.
Relevance for bioenergy sector	Support in development of provincial bioenergy policy and planning, as well as mainstreaming bioenergy projects in accordance with the available resources and in response to energy needs of the province. Cooperation and coordination with the federal government.
Relevance for biomass mapping	Provision of statistical data on the production of crops and respective residues of interest for bioenergy production, including production areas, yields, residue-to-crop ratio or harvesting index, level of current utilization of the residues (as feed, bedding, construction material, etc.) and other. Provision of planned agricultural production in the short-, medium- and long-term and support for continuous monitoring and updating of biomass maps.
FORESTRY, WILDLIFE AND FISHERIES DEPARTMENT	
Mandate	Responsible for developing, maintaining, conserving and maximizing forestry sector resources in the province.
Relevance for bioenergy sector	Support in development of provincial bioenergy policy and planning. Streamlining sustainable forest management and woodfuel utilization. Cooperation and coordination with the federal government.
Relevance for biomass mapping	Provision of information on forestry statistics (forest inventories, current and planned harvesting, trade), wood processing statistics, characteristics of processing facilities in the country and current use of forest harvesting and wood processing residues. These are the baseline data for estimation and mapping of woody biomass to be available for bioenergy production.
LIVESTOCK AND DAIRY DEVELOPMENT DEPARTMENT	
Mandate	Support to the growth and development of livestock sector in the province thus contributing to national food security, economic uplift, rural development, poverty alleviation and employment generation.
Relevance for bioenergy sector	Promotion of biogas production as manure management practice and additional source of energy and/or income for livestock producers. Capacity building of livestock producers and other relevant stakeholders (investors, technology providers, etc.) Support in biogas policy development and implementation of biogas project in the province and coordination with federal government.
Relevance for biomass mapping	Provision of information on livestock production (number of animals in commercial and household production, characteristics of the production

	systems in the province), locations of the livestock farms and dairy facilities.
BUREAU OF STATISTICS	
Mandate	Responsible for collection, processing and dissemination of statistical data through surveys, periodic publications and electronic media.
Relevance for biomass mapping	Provision of statistical relevant statistical data and implementation of surveys if the necessary data is not available.
ENERGY DEPARTMENT	
Mandate	Responsible for regulating the power sector and developing power projects through public or private sector investment, mostly oil and gas projects.
Relevance for bioenergy sector	Integration of biomass power plants into the provincial power system, development of and/or support to bioenergy production facilities.
Relevance for biomass mapping	Provision of information on the existing energy infrastructure (production facilities, transmission, distribution), areas where additional electricity supply is needed and detailed information about the possibilities for connecting new production facilities to the grid or establishment of isolated grids.

7.1.2 Sindh Province

Sindh is located in the southeastern part of Pakistan. According to the population, it is the second largest province after Punjab. The current population is estimated at 42.2 million (Population Welfare Department, Government of Sindh, 2014). Agriculture is still the basis of the economy, although industry substantially contributes to the province's GDP. Cotton, wheat, rice, sugarcane, maize, millet, and oilseeds are the major crops in the province, livestock raising is also important. The most important agro-industries are cotton processing and sugar mills.

The provincial government has 27 departments. The departments relevant for biomass mapping and bioenegy sector development are the Agriculture, Supply and Prices Department, Forest, Environment and Wildlife Department, Energy Department and the Bureau of Statistics. An overview, including the departments' mandates and relevance for biomass mapping and sector development is given in the following tables. A list of all Provincial departments, with links to their official web site, can be found in the Annex II.

Table 24: Sindh Province Departments relevant to bioenergy

THE AGRICULTURE, SUPPLY AND PRICES DEPARTMENT	
Mandate	Responsible for agriculture research, advancement of mechanized agriculture, providing strong market information system, improving agriculture extension service and managing water and irrigation systems.
Relevance for bioenergy sector	Support in development of provincial bioenergy policy and planning, as well as mainstreaming bioenergy projects in accordance with the available resources and in response with energy needs of the province. Capacity building and support to farmers involved in bioenergy sector through extension services. Cooperation and coordination with the federal government.
Relevance for biomass mapping	Provision of statistical data on the production of crops and respective residues of interest for bioenergy production, including production areas, yields, residue-to-crop ratio or harvesting index, level of current utilization of the residues (as feed, bedding, construction material, etc.) and other.

	Provision of planned agricultural production in the short-, medium- and long-term and support for continuous monitoring and updating of biomass maps.
FOREST, ENVIRONMENT AND WILDLIFE DEPARTMENT	
Mandate	Conservation and improvement of the existing forests and rangelands to ensure sustainable production in the forest ecosystem areas, meet the fuel wood and timber requirements of the province, conduct basic and applied research on various forestry aspects and disseminate information to stakeholders, and create awareness to the general public on preserving biodiversity and forest conservation.
Relevance for bioenergy sector	Support in development of provincial bioenergy policy and planning. Streamlining sustainable forest management and woodfuel utilization. Cooperation and coordination with the federal government.
Relevance for biomass mapping	Provision of information on forestry statistics (inventories on forests and trees outside forests, current and planned harvesting, trade), wood processing statistics, characteristics of processing facilities in the country and current use of forest harvesting and wood processing residues. These are the baseline data for estimation and mapping of woody biomass available for bioenergy production.
BUREAU OF STATISTICS	
Mandate	Responsible for collection, processing and dissemination of statistical data through surveys, periodic publications and electronic media.
Relevance for bioenergy sector	Provision of relevant statistical data and implementation of surveys if the necessary data is not available
ENERGY DEPARTMENT	
Mandate	Responsible for solving matters related to development, generation, supply and distribution of hydro and thermal power, and policy formulation, perspective planning, processing of power projects and enactment of legislation in the power sector. **Village Electrification Programme:** Responsible for identifying and prioritizing the un-electrified villages of Sindh, preparing feasibility studies, providing funds and executing the electrification work.
Relevance for bioenergy sector	Integration of biomass power plants into the provincial power system, development of and/or support to bioenergy production facilities.
Relevance for biomass mapping	Provision of information on the existing energy infrastructure (production facilities, transmission, distribution), areas where additional electricity supply is needed and detailed information about the possibilities for inclusion of new production facilities in the grid or establishment of isolated grids.

7.1.3 Balochistan Province

Balochistan, the westernmost and the largest of the four provinces of Pakistan, spreads over an area of 347,190 km^2 thus forming 43.6 percent of the total country area. It is sparsely populated, with a population of about 8 million (PDMA Balochistan, Balochistan Profile). The economy of the province is largely based on livestock breeding, cropping, fisheries and production of natural gas, coal, and minerals. Crop production is limited by the scarcity of water, power, and adequate transportation facilities. Wheat, sorghum, and rice are the major food crops, and fruits are the principal cash crops.

Sheep-raising employs the great majority of the population and occupies most of the land. Almost all industry is small scale; it includes cotton and woolen manufacturing, food processing, carpet making, textile and leather embroidery, small machinery and appliance manufacturing, and handicrafts. The transportation network is poorly developed.

The Government of Balochistan comprises 39 departments of which five are directly relevant for bioenergy sector development: the Department of Energy, Agriculture and Cooperatives Department, Forest and Wildlife Department, Livestock and Dairy Development and the Food Department. Some of the sections of the Planning and Development department may also play a role in planning, progress reviewing, monitoring and evaluation of bioenergy projects implemented in the province. Tables below include a description of the current mandates of the departments and their relevance for the bioenergy sector and biomass mapping. A list of all Provincial departments, with links to their official web site, can be found in the Annex II.

Table 25: Balochistan Province Departments relevant to bioenergy

THE AGRICULTURE AND COOPERATIVES DEPARTMENT	
Mandate	Transmission of modern crop technology and agricultural techniques to the growers and provision of extension services, agricultural research and setting of model farms, assistance to the Crop Reporting Services (CRS) in conducting surveys, collection of data, and Helping farmers in taking remedial measures against pest attack.
Relevance for bioenergy sector	Support in development of provincial bioenergy policy and planning, as well as mainstreaming bioenergy projects in accordance with the available resources and in response with energy needs of the province. Cooperation and coordination with the federal government.
Relevance for biomass mapping	Provision of information on the agricultural production, past, current and potentially attainable yields of crops, crop residues production (residue-to-crop ratio) and the level of their use.
FOREST AND WILDLIFE DEPARTMENT	
Mandate	Conservation and development of natural resources to ensure sustainable development and a continuous supply of goods and services for the people in the province.
Relevance for bioenergy sector	Support in development of provincial bioenergy policy and planning. Streamlining sustainable forest management and woodfuel utilization. Cooperation and coordination with the federal government.
Relevance for biomass mapping	Provision of information on forestry statistics (inventories on forests and trees outside forests, current and planned harvesting, trade), wood processing statistics, characteristics of processing facilities in the country and current use of forest harvesting and wood processing residues. These are the baseline data for estimation and mapping of woody biomass be available for bioenergy production.
DEPARTMENT OF ENERGY	
Mandate	Responsible for meeting energy needs in the province by using available resources (hydro, oil and gas energy resources), and by exploring sustainable alternative energy sources through initiating renewable energy projects. Responsible for providing electricity to underdeveloped/rural areas of the

	province.
Relevance for bioenergy sector	Support to the planning and implementation of bioenergy projects, especially in the underdeveloped/rural areas of the province.
Relevance for biomass mapping	Provision of information on the existing energy infrastructure (production facilities, transmission, distribution), areas where additional electricity supply is needed.
PLANNING AND DEVELOPMENT DEPARTMENT	
Mandate	Planning including policy and development. Co-operation of technical assistance from abroad. Economic research (and matters relating to Board of Economic Inquiry). Co-operation of statistics in General, and all matters relating to the Bureau of Statistics. Processing of all development schemes, programs and proposals submitted by other Departments and making recommendations to Government thereon. Dissemination of information and education.
Relevance for bioenergy sector	Provision of information about the ongoing energy and bioenergy initiatives, streamlining of bioenergy projects into the development plans and dissemination of information.
Relevance for biomass mapping	Provision of statistical data.

7.1.4 Khyber-Pukhtunkhwa (KPK) Province

Khyber Pakhtunkhwa (KPK) is in the north-west of the country spread over 74,521 km^2, with an estimated population of 24.7 million in 2010, (UNDP, 2011). Forests cover about 17.4 percent, while 48 percent of the land is used as rangelands and pastures and about 30 percent for crop cultivation. Agriculture is the main economic activity, contributing 20 percent to the provincial GDP and employing 44 percent of the labour force. The main agricultural commodities are tobacco, sugarcane, maize and fruits. Compared to other provinces, KPK is less industrialized, the main products being cigarettes and cements (UNDP, 2011). The provincial government includes more than 30 departments of which five are directly relevant for the bioenergy sector development and biomass mapping: Agriculture, Livestock and Cooperation Department, Food Department, Forest Department, Energy and Power Department and the Planning and Development Department. Their relevance for biomass mapping and sector development is described in the tables below, while a list of all Provincial departments, with links to their official web site, can be found in the Annex II.

Table 26: KPK Province Departments relevant to bioenergy

AGRICULTURE, LIVESTOCK AND COOPERATION DEPARTMENT	
Mandate	Responsible for developing the agricultural sector, including the livestock sub-sector, formulating and implementing policies and programs and exercising administrative and financial control over the departments.
Relevance for bioenergy sector	Support in development of bioenergy policy, programs and plans and coordination with federal government. Mainstreaming bioenergy projects in accordance with the available resources, and in response with energy needs of the province.
Relevance for biomass mapping	Provision of information on the production of crops, generation and use of crop residues; information about livestock production systems and location of major livestock and dairy producers.

FOOD DEPARTMENT	
Mandate	Responsible for the procurement, storage and distribution of wheat, sugar, rice and other essential commodities, and fixation of prices through controlling production and supply of the products to make them affordable to consumers
Relevance for bioenergy sector	Support to development of bioenergy policy and projects so as to ensure food security.
FOREST DEPARMENT	
Mandate	Preparation and implementation of policies and programmes in forestry sector. Implementation of Forestry Law and rules. Protection, conservation and development of renewable natural resources, particularly forests and range lands in the province. Demarcation and protection of Forest lands against encroachment. Raising of nurseries and plantations. Managing forests, wastelands and rangelands in the province. Preparation of strategic, operational and local plans for effective management of forests. Conducting applied research and promotion of non-timber forest products. Organizing communities into self-managing local organizations through VLUP & JFM approaches. Human Resource Development. Inter provincial coordination with the Federal Government.
Relevance for bioenergy sector	Support in development of provincial bioenergy policy and planning. Streamlining sustainable forest management and woodfuel utilization. Cooperation and coordination with the federal government.
Relevance for biomass mapping	Provision of information on forestry statistics (inventories on forests and trees outside forests, current and planned harvesting, trade), wood processing statistics, characteristics of processing facilities in the country and current use of forest harvesting and wood processing residues. These are the baseline data for estimation and mapping of woody biomass be available for bioenergy production.
ENERGY AND POWER DEPARMENT	
Mandate	Responsible for monitoring the physical and financial progress of hydropower projects and oil and gas projects, granting licenses to companies and advising the provincial Government on energy and power matters.
Relevance for bioenergy sector	Support to the planning and implementation of bioenergy projects, and their inclusion in the power system. Cooperation and coordination with the federal government.
Relevance for biomass mapping	Provision of information about the existing and planned power projects, energy infrastructure and energy needs in the province.
PLANNING AND DEVELOPMENT DEPARTMENT	
Mandate	Responsible for the implementation and monitoring of the overall development plans of the Province.
Relevance for bioenergy sector	Provision of information about the ongoing energy and bioenergy initiatives, streamlining of bioenergy projects into the development plans and dissemination of information.
Relevance for biomass mapping	Provision of statistical data.

7.2 ANNEX II: Contact details and links

Table 27: Federal Government Ministries and Divisions of Pakistan (Source: Government of Pakistan, 2014)

Ministry	Division
Cabinet Secretariat	- Cabinet Division - Establishment Division - Climate Change Division - Capital Administration & Development Division - Aviation Division
Finance, Revenue, Economic Affairs, Statistics and Privatization	- Finance Division - Economic Affairs Division - Revenue Division - Statistics Division - Privatization Division
Ministry of Planning and Development	- Planning and Development Division
Ministry of Commerce and Textile Industry	- Commerce Division - Textile Industry Division
Ministry of Communications	- Communications Division
Ministry of Defence	- Defence Division
Ministry of Defence Production	- Defence Production Division
Ministry of Education, Trainings and Standards in Higher Education	- Education,Trainings and Standards in Higher Education Division
Ministry of Foreign Affairs	- Foreign Affairs Division
Ministry of Housing & Works	- Housing & Works Division
Ministry of Industries and Production	- Industries Division
Ministry of Information, Broadcasting and National Heritage	- Information, Broadcasting and Heritage Division
Ministry of Information Technology and Telecommunication	- IT & Telecom Division
Ministry of Inter Provincial Coordination	- Inter Provincial Coordination Division
Ministry of Interior and Narcotics Control	- Interior Division - Narcotics Control Division
Ministry of Kashmir Affairs and Gilgit Baltistan	- Kashmir Affairs and Gilgit Baltistan Division
Ministry of Law , Justice Law and Human Rights	- Law, Justice and Human Rights Division
Ministry of Overseas Pakistanis and Human Resource Development	- Overseas Pakistanis and Human Resource Development Division
Ministry of Petroleum & Natural Resources	- Petroleum & Natural Resources Division
Ministry of Ports and Shipping	- Ports and Shipping Division
Ministry of Railways	- Railways Division
Ministry of Religious Affairs and Inter-faith Harmony	- Religious Affairs and Inter-faith Harmony Division
Ministry of Science and Technology	- Scientific & Technological Research Division
Ministry of States and Frontier Regions	- States and Frontier Regions Division
Ministry of Water & Power	- Water & Power Division
Ministry of National Health Services Regulation and Coordination	- National Health Services Regulation and Coordination Division.
Ministry of National Food Security and Research	- National Food Security and Research Division.
Ministry of Parlimentary Affairs	- Parlimentary Affairs Division

Table 28: Departments of the Government of Punjab (Source: Government of Punjab Province, 2014)

Departments	
Agriculture	Labour and Human Resource
Auqaf and Religious Affairs	Law and Parliamentary Affairs
Board of Revenue	Literacy and Non Formal Basic Education
Chief Minister's Inspection Team	Livestock and Dairy Development
Communications and Works	Local Government and Community Development
Cooperatives	Management and Professional Development
Energy	Mines and Minerals
Environment Protection	Planning and Development
Excise and Taxation	Population Welfare
Finance	Public Prosecution
Food	School Education
Forestry, Wildlife and Fisheries	Services and General Administration
Health	Social Welfare and Bait-ul-Maal
Higher Education	Special Education
Home	Transport
Housing, Urban Development and Public Health Engineering	Women Development
Human Rights and Minorities Affairs	Youth Affairs, Sports, Archeology & Tourism
Industries, Commerce and Investment	Zakat and Ushr
Information and CultureIrrigation	

Table 29: Departments of the Government of Sindh (Source: Government of Sindh Province, 2014)

Provincial departments of the Government of Sindh Province	
Agriculture, Supply & Prices Department	Labour & Human Resources Department
Auqaf, Religious Affairs, Zakat & Ushr Department	Law, Parliamentary Affairs & Human Rights Department
Board of Revenue	Livestock & Fisheries Department
Chief Minister's Secretariat	Local Government, Rural Development,PHE & HTP Department
Thar Coal & Energy Board	Mines & Minerals Development Department
Cooperation Department	Minorities Affairs Department
Culture,Tourism &Antiquities Department	Planning & Development & Special Initiatives Department
Excise,Taxation & Narcotics Department	Population Welfare Department
Finance Department	Rehabilitation Department
Food Department	Health Department
Forest, Environment & Wildlife Department	SGA & CD
Governor's Secretariat	Social Welfare Department
Higher, Technical Education & Research & School Education Department	Special Education Department
Home Department	Sports & Youth Affairs Department
Information & Archieve Department	Transport & Mass Transit Department
Information, Science & Technology Department	Women Development Department
Industries & Commerce	Works & Services Department
Irrigation Department	
Katchi Abadies Department	

Table 30: Departments of the Government of Balochistan (Source: Government of Balochistan, 2014)

Provincial departments of the Government of Sindh Province	
Agriculture & Cooperatives	Law & ParliamentaryAffairs
Culture, Tourism &Archives	Mines & Mineral
Finance	Energy
Forest &Wildlife	Provincial Transport Authority
Home & Tribal Affairs	Services & General Administration
Board of Revenue	Urban Planning & Development
Labour &Manpower	Printing & Stationery
Local Government &Rural Development	Communication, Works,Physical Planning & Housing
Population Welfare	Environment, Sports &Youth Affairs
Provincial Disaster Management Authority	Food
Science & Information Technology	Health
Civil Defence	Information
Women Development	Irrigation
Chief Minister's Inspection Team	Livestock & DairyDevelopment
Education	Planning &Development
Fisheries	Prosecution
Religious Affairs and Inter Faith Harmony	Public Health Engineering
Industries &Commerce	Social Welfare, Special Education, Literacy/Non-Formal Education and Human Rights
Inter ProvincialCoordination	Excise and Taxation

Table 31: Departments of the Khyber-Pukhtunkhwa (KPK) (Source: Government of KPK Province, 2014)

Provincial departments of the Government of Sindh Province	
Administration	Agriculture
Auqaf	Establishment
Excise & Taxation	Environment
Elementary & Secondary Education	Finance
Food	Health
Home & Tribal Affairs	Higher Education
Housing	Industries
Law	Local Government
Planning & Development	Population Welfare
Revenue	Science & Technology and Information Technology
Tourism	Communication & Works(C&W)
Zakat Ushr	Social Welfare
Engery & Power	Transport
Information & Public Relations	Minerals Development
Irrigation	Inter Provincial Coordinationl
Labor	Relief, Rehabilitation & Settlementl
Public Health Engineering	

7.3 ANNEX III: List of biomass projects with electricity generation licence

The following table includes a list of planned bioenergy production facilities which were awarded generation licence by National Electric Power Regulatory Authority (NEPRA).

Table 32: List of biomass projects with electricity generation licence (Source: NEPRA, 2014)

Name of the file	Issue Date	Location	Plant Size (MW)	Expected lifetime (year)	Primary Fuel	Alternate Fuel
LAG-66	08/02/2005	Plot No.H-23/3 Industrial Area, Landhi, Larachi	5.88 (5x0.635MW + 3x0.900MW)	24	Natural Gas	Natural Gas
LAG-121	28/04/2009	38-Km, Jhang-Muzzafargarh Road, Dargai Shah, District Jhang, Punjab	20.00	20	Bagasse	Firnace Oil(FO)
LAG-182	08/01/2014	Opposite Al-Abbas Sugar Mills Limited in the town of Mirwah Gorchani, District Mirpurkhas, in the Province of Sindh	12.00	30	Bagasse/Rice Husk	Cotton Stalk/Wood Chips etc.
LAG-204	27/07/2012	3.3-KM Jhang-Chinoiot Road, District Jhang, in the Province of Punjab	12.00	30	Cotton Stalk/Rice Husk	Cotton Stalk/Wood Chips etc.
LAG-208	30/08/2012	Deh Jagsiyani, Taluka Matli, District Tando Muhammad Khan, Sindh	9.132 (3x3.044MW)	25	Biogas	Not Applicable (N/A)
LAG-232	27/09/2013	Machi Goth, Tehsil Sadiqabad, District Rahim Yar Khan, in the Province of Punjab	26.35	30	Biogas	Biomass
LAG-247	11/06/2014	26-KM Chiniot-Jhang Road, Tehsil and District Chiniot in the Province of Punjab	62.40 (2x31.20MW)	30	Bagasse	Biomass
LAG-253	10/09/2014	Janpur, Tehsil Liaquat Pur, District Rahimyar Khan in the Province of Punjab	30.00 (2*15MW)	30	Bagasse	Furnace Oil
LAG-257	12/09/2104	Jetha Bhutta, Tehsil Khanpur, District Rahimyar Khan, in the Province of Punjab	30.00 (2*15MW)	30	Bagasse	Furnace Oil

8 REFERENCES

AEBIOM, 2014. Official web site. Available at: www.aebiom.org/blog/category/about_us/about_bioenergy/. Last accessed: July 2014

Alternative Energy Solution Providers (presented in 2012). Development of market based approach for utilization of biomass in industrial power generation.

Belgiorno, V. et al. 2003. Energy from Gasification of Solid waste, Waste Management, Vol. 23, pps: 1–15.

EUBIONET (2003), Biomass Co-firing: an efficient way to reduce greenhouse gas emissions, EU.

FAO, 2004a: Unified Bioenergy Terminology, UBET.

FAO, 2004b. Fertilizer Use by Crop in Pakistan. Available at: www.fao.org/docrep/007/y5460e/y5460e00.htm#Contents. Last accessed: July 2014

FAOSTAT, 2014a. Food Balance Sheet for 2011

FAOSTAT, 2014b. Animal production

FAO, 2014. BEFS Rapid Appraisal – Introduction, Natural Resources Module (Manuals). Available from: http://www.fao.org/energy/befs/86187/en/. Last accessed: September 2014.

Federal Bureau of Statistics, 2010. Crops area and production (by districts) (1981-82 to 2008-09) Volume I Food and Cash Crops. Government of Pakistan

GEF-UNIDO, 2010. Pre-feasibility Study: Promoting sustainable energy production and use from biomass in Pakistan to meet Energy Needs of SMEs and Rural Electrification

GIEW, 2014. GIEW Country Briefs: Pakistan. Available from: http://www.fao.org/giews/countrybrief/country.jsp?code=PAK. Last accessed: July 2014

Government of Pakistan, Ministry of Water and Power, 2013. National Power Policy. Available at http://www.ppib.gov.pk/National%20Power%20Policy%202013.pdf. Last accessed: September 2014

Government of Pakistan, 2014. Official web site. Available at http://www.pakistan.gov.pk/. Last accessed: July 2014

Government of Pakistan, Ministry of Finance, 2014. Pakistan Economic Survey 2013 – 14.

Hydrocarbon Development Institute of Pakistan, 2013: Pakistan Energy Yearbook 2012. Pakistan Ministry of Petroleum and Natural Resources.

IEA, 2008. Combined Heat and Power: Evaluating the Benefits of Greater Global Investment, IEA/OECD, Paris.

IEA, 2014. Energy Statistics, Energy Balance for Pakistan

IEA Bioenergy , 2009. Bioenergy - a Sustainable and Reliable Energy Source: A review of status and prospects.

IPCC, 2006. Guidelines for National Greenhouse Gas Inventories, Vol.4, Annex 10A.2

Kurkela, E. 2010. Thermal Gasification for Powerand Fuels, VTT, Finland.

Lettner, F., H.Timmerer and P. Haselbacher, 2007. Biomass gasification –State ofthe art description, Graz University of Technology – Institute of Thermal Engineering, Graz, Austria.

McHale Performance (2010), Biomass Technology Review, Biomass Power Association, USA.

OrdinanceSurvey, 2014. Official web site. Available at: www.ordnancesurvey.co.uk/support/understanding-gis/raster-vector.html. Last accessed: July 2014

PAKARAB, 2014. Crops in Pakistan. Available at: www.fatima-group.com/pakarabfertilizers/crop.php. Last accessed: July 2014

Pakistan Bureau of Statistics, 2014. Agricultural Statistics of Pakistan 2010-11. Available at: www.pbs.gov.pk/content/agricultural-statistics-pakistan-2010-11. Last accessed: July 2014

PDMA Balochistan,2014. Balochistan Profile. Available at: www.pdma.gob.pk/?p=39. Last accessed: July 2014

Population Welfare Department, Government of Sindh, 2014. Official web site. Available at: www.pwdsindh.gov.pk/. Last accessed: July 2014

Rensfelt, E. (2005), State of the Art of Biomass Gasification and Pyrolysis Technologies,Proceedings of Synbios Automobile Conference, Stockholm.

Rosillo-Calle, Frank; de Groot, Peter; Hemstock, Sarah L.; Woods, Jeremy, 2008: Biomass Assessment Handbook - Bioenergy for a Sustainable Environment Routledge.

Sadaka, S., 2010. Gasification, Producer Gas, and Syngas, Agricultural and Natural Resources, University of Arkansas, USA.

SECOM, 2012: Pulp and Paper Industry in Pakistan. Available from sistemas.mre.gov.br/kitweb/datafiles/Islamabade/en-us/file/Pulp%20and%20%20Paper%20Industry%20in%20Pakistan-Final%281%29.pdf. Last accessed: July 2014.

The World Bank, 2014. World Development Indicators.

UNDP, 2011: Khyber Pakhtunkhwa, Millennium Development Goals, 2011 Report. www.undp.org/content/dam/pakistan/docs/MDGs/UNDP-PK-MDG-KP-2011.pdf Last accessed: July 2014

UNIDO, 2008. Guidebook on Modern Bioenergy Conversion Technologies in Africa, UNIDO, Vienna.

UNIDO, 2009. Deployment of Technologies for Sustainable Bioenergy: Towards an Agenda for International Cooperation, UNIDO, Vienna.

US EPA, 2007. Combined Heat and Power: Catalogue of Technologies. U. S. Environmental Protection Agency, USA.

Vis, M.W. and D. van den Berg, 2010. BEE Best Practices and Methods Handbook. Available from: www.uvm.edu/~cdl/2012workshop/BEE%20Biomass%20Methods%20Handbook%202010.pdf Last accessed: July 2014.

Younas, M. and Yaqoob,M. 200?. Rural livestock production in Pakistan. Available at: www.pakissan.com/english/allabout/livestock/rural.livestock.pakistan.shtml. Last accessed: July 2014

Zia, U.E., 2010. Pakistan: A dairy sector at a crossroads in FAO 2010, Smallholder dairy development: Lessons learned in Asia. Available at: www.fao.org/docrep/011/i0588e/I0588E00.htm#Contents. Last accessed: July 2014

Official websites of Federal and Provincial governments

Government of Pakistan	www.pakistan.gov.pk/
Government of Punjab Province	www.punjab.gov.pk/provincialdepartments
Government of Sindh Province	http://sindh.gov.pk/
Government of Balochistan Province	http://balochistan.gov.pk
Government of KPK Province	www.khyberpakhtunkhwa.gov.pk/Gov/Departments.php