Possible Uses of Crop Residue for Energy Generation Instead of Open Burning

SAARC Energy Centre

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SAARC Energy Centre
697, St. 43, E-11/4 (NFP), Islamabad, Pakistan
Tel: + (92 51) 222 2089. Fax: + (92 51) 222 1937
Email: info@saarcenergy.org

Also available on Website
www.saarcenergy.org

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STUDY COORDINATOR
Mr. Ihsanullah Marwat (Research Fellow – Energy Efficiency)

LEAD REVIEWER
Mr. Tula Ram Poudel (Research Fellow – Energy Trade)

Website: https://www.saarcenergy.org/

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Foreword

In the SAARC Member States agricultural practices contribute to over 20% of their GDP and is a source of subsistence to over 60% of the population. Rice-wheat cropping system is dominant in South Asia, mainly in Pakistan, India, Bangladesh, and Nepal, resultantly produces enormous quantity of rice and wheat straw residues in the fields. To prepare the fields for next cultivating season, the left-over residue is usually burnt by farmers in the open air. This results in large amount of GHG emissions, which when combines with dense winter fog, contributes to atmospheric smog. The rising issue of smog has led to severe health and environmental problems. To counter these environmental and health impacts, we need to find out techno-economic solutions to utilize crop residue effectively instead of burning it in open air. A few studies indicate the potential of electricity generation using crop residue as a fuel in thermal power plants. Similarly, synthesis gas can be produced from crop residue, which can be supplied to the rural community for cooking and heating purposes.

In this context, the SAARC Energy Centre (SEC) initiated this study on the "Possible uses of crop residue for energy generation instead of open burning" to explore the possibility of generating energy using various technologies/ techniques. The study provides a country wise review of agricultural practices, overall crop production, gross residue generation, and existing utilization & disposal practices. The potential crops for energy generation have been selected using a combination of factors such as area under cultivation, annual production of crop, estimated residue potential and surplus residue, and energy content of residue. To estimate "Surplus Crop Residue" of respective crop, Residue Production Ratio (RPR) has been used. Collection, storage, transportation, and associated costs are also discussed in detail, which are used for estimation of energy generation potential. Based on RPR and heating values of surplus crop residue, various suitable energy generation technologies are discussed in detail, which helped in identifying most feasible technology to be used for energy generation. Additionally alternative uses of crop residue such as paper and pulp manufacturing, briquetting, compost, and fertilizers etc., are also covered in detail.

The study findings show that, over 114 million Tons of crop residue is burnt every year in the SAARC region (predominantly in India, Pakistan, Bangladesh, and Nepal). These crop residues have a potential to generate 7,598 MW of energy. To tap this potential "Gasification" has been proposed as preferred choice with relative lowest capital cost and cost of generation i.e., USD 0.12-0.13/kWh. A detailed business model and country wise implementation plan, covering various parameters, has been recommended in the study for each of the SAARC Member States. For successful implementation the author identified few country-specific barriers such as market factors, financial challenges, technical support, and institutional challenges that need to be looked for. In the end to overcome these barriers, specific recommendations have also been included in study report for consideration of stakeholders.

Dr Nawaz Ahmad Virk
Director,
SAARC Energy Centre

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List of Abbreviations

Acronym	Meaning
ADS	Agriculture Development Strategy
ALRI	Acute Lower Respiratory Infections
AQI	Air Quality Index
ARI	Acute Respiratory Infection
BM	Build and maintain
BOM	Build Own and Maintain
BOO	Build Own and Operate
BOOM	Build Own Operate and Maintain
BOP	Balance of Plant
BOT	Build Own Transfer
BPCL	Bharat Petroleum Corporation Limited
BTG	Boiler Turbine Generator
CAGR	Compound annual growth rate
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CNG	Compressed natural gas
COPD	Chronic obstructive pulmonary disease
CPCB	Central Pollution Control Board
DBO	Design Build Operate
DFO	District Forest Officials
Discoms	Distribution Companies
DM	De-Mineralization
EAI	Energy Alternatives India
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
GCV	Gross Calorific Value
GDP	Gross Domestic Product
GHG	Greenhouse gas
GIEWS	Global Information and Early Warning System
GRP	Gross Residue Potential

Acronym	Meaning
GVA	Gross Value Added
GW	Giga watt
HPCL	Hindustan Petroleum Corporation Limited
HPHT	High Pressure High Temperature
HPS	Husk Power Systems
ICE	Internal Combustion Engine
ICICI	Industrial Credit and Investment Corporation of India
IDBI	Industrial Development Bank of India
IGP	Indo-Gangetic Plain
INR	Indian National Rupee
IOCL	Indian Oil Corporation Limited
IREDA	Indian Renewable Energy Development Agency
IRENA	International Renewable Energy Agency
KEVPL	Kalpataru Energy Venture Private Limited
kV	kilo Volt
kW	kilo Watt
kWh	Kilo Watt hour
MAIL	Ministry of Agriculture, Irrigation and Livestock
MJ	Mega Joule
$MMTCO_2e$	million metric tons of carbon dioxide equivalent
$MMTCH_4e$	million metric tons of methane equivalent
MNRE	Ministry of New and Renewable Energy
MoA	Ministry of Agriculture
MoAD	Ministry of Agriculture and Livestock Development
MoAF	Ministry of Agriculture and Forests
MoAFW	Ministry of Agriculture and Farmers Welfare
MOEF&CC	Ministry of Environment, Forest and Climate Change
MoFA	Maldives, Ministry of Fisheries and Agriculture
MoNFS	Ministry of National Food Security & Research
MoRD	Ministry of Rural Development
MRPL	Mangalore Refinery and Petrochemicals Limited
MSW	Municipal Solid Waste

Acronym	Meaning
MT	Metric Tons
MU	million Units
MW	Mega watt
MWh	Megawatt hour
NABARD	National Bank for Agriculture and Rural Development
NASA	National Aeronautics and Space Administration
NCD	Non-communicable Disease
NMHC	Non-methane hydrocarbon
NPMCR	National Policy for Management of Crop Residues
NRSA	National Remote Sensing Agency
NTPC	National Thermal Power Corporation
O&M	Operation and Maintenance
PFC	Power Finance Corporation
PLF	Plant Load Factor
PM	Particulate Matter
PMKSY	Pradhan Mantri Krishi Sinchayee Yojana
PPA	Power Purchase Agreement
R&D	Research and Development
RPR	Residue Production Ratio
RVPN	Rajasthan Rajya Vidyut Prasaran Nigam Limited
SAARC	South Asian Association for Regional Cooperation
SDPI	Sustainable Development Policy Institute
SEC	SAARC Energy Center
SFC	Specific Fuel Consumption
SME	Small and Medium Enterprises
SMS	Straw Management System
SRP	Surplus Residue Potential
SVOC	Semi-Volatile Organic Compounds
T&D	Transmission and Distribution
TERI	The Energy Research Institute
TG	Turbine Generator
TJ	Tera Joule

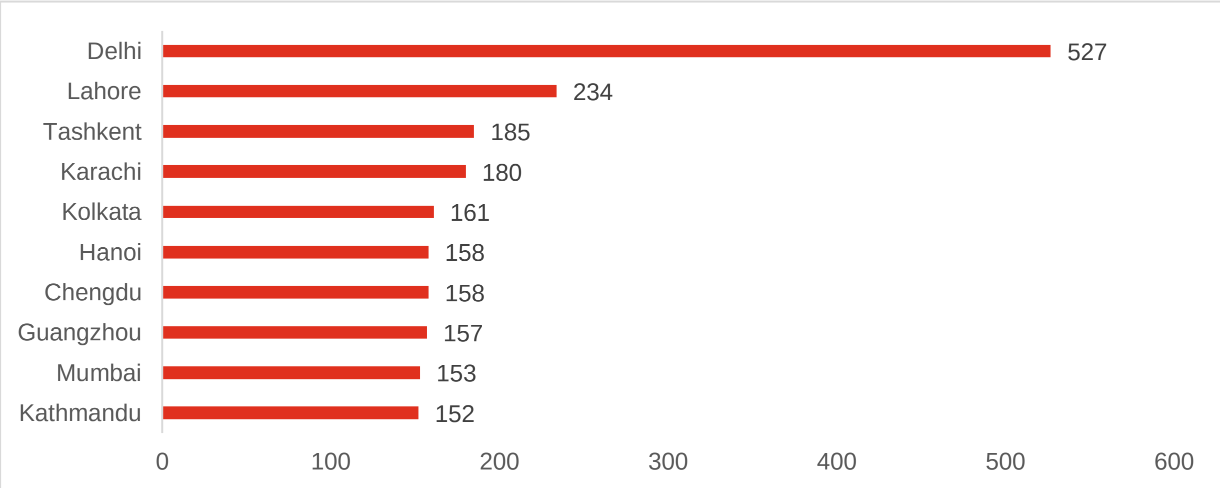
Acronym	Meaning
TPH	Tons Per Hour
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
USD	United States Dollar
VESP	Village Energy Security Program
VGF	Viability Gap Funding
VOC	Volatile Organic Compounds
WHO	World Health Organization
Y-O-Y	Year on Year

Executive Summary

Agriculture sector is the backbone of most SAARC Member States, contributing to 15-20% of their GDP and a source of subsistence to 60-70% of the population. The year-round crop cultivation generates a large amount of agricultural waste and resultant crop residue of around 450-500 million Tons.

In the absence of alternate residue management practices and strict law enforcement, around 70-80% of the crop residue is burnt in the fields by the farmers, causing GHG emissions and air pollution. This issue is most noticeable in the Northern parts of India in states of Haryana, Punjab and Delhi and Eastern provinces of Pakistan in Punjab and Sindh, where rice-wheat farming is common. Resultantly, the air pollution has gone up to catastrophic levels in many large cities in the region. As on November 26, 2019, six cities from India, Pakistan and Nepal featured in the top ten most polluted cities around the world in terms of Air Quality Index (AQI).

Figure 1: US Air Quality Index



Main causes of crop residue burning are two-fold: timely sowing of wheat within a window of only 2-3 weeks and lack of manpower for efficient straw cutting. Each year, air pollution from this crop residue burning in parts of India, Pakistan, Nepal, and Bangladesh poses a recurring and growing threat, leading to massive winter pollution1, and health & safety hazards in the South Asian region. According to a study conducted by GeoHealth, premature mortality attributed to exposure to ambient particulate matter in India alone is 1.1 million each year, and nearly half of these deaths occur in Indo-Gangetic Plain and northern part of the country.

The rising problems associated with pollution from the crop residue burning have initiated exploration of alternative uses of this residue. Traditionally, small portion of the crop residue is used as cattle fodder, cooking fuel, animal bedding and paper production, however, around 75-80% of the quantity continues to be burnt in-situ. Other efficient ways of disposal of the residue include production of biogas, bio-oil, and energy generation. Considering ever increasing energy demand in South Asia, energy generation using crop residue can be a sustainable option for effective residue utilization. The strength of bioenergy programs in these countries lies in their enormous potential for agriculture and their resulting crop residue generation. Different means and methods of utilizing crop residue for energy generation purposes have been explored in this study, to curb the hazards of burning such crop residue.

[1] Caused by a combination of smoke from the burning of crop residue and heavy fog in the Northern regions of Indo-Gangetic Plain, most noticeable in Delhi, Punjab and Haryana and Eastern region of Pakistan

Potential Considerable quantity of agricultural residue is available in certain identified regions in the SAARC countries. The table below illustrates the total crop production and resultant gross/ surplus residue production potential in Member States. Among all SAARC Member States, India has the highest residue production followed by Pakistan and Bangladesh, owing to their large geographical areas. The crop residue potential of Maldives is negligible owing to its distributed island geography.

Table 1: Gross and Surplus Residue Production Potential using all the Crops in SAARC Member States

Member State	Total crop production (million Tons)	Gross Residue Production (million Tons)	Surplus Residue Production (million Tons)
Afghanistan	5.6	9.7	2.2
Bangladesh	81.5	99.6	24.3
Bhutan	0.4	0.4	0.1
India	744.3	912	300
Nepal	17.2	22.8	6.3
Pakistan	128.7	122.8	37.3
Sri Lanka	3.2	4.7	1.3
Total	**981**	**1,172**	**372**

It is observed that most crop residue burning in the SAARC Member States is practiced for rice stubble in the months of October- November, for timely sowing of the wheat crop, usually within a window of 2-3 weeks. The pattern is repeated when the wheat stubble is burnt in the fields in the months of May-June. The burning of these two crops' residues is the major contributor for excessive GHG emissions and air pollution along with smog in the winters.

Since the field-based residue like straws, stalk and leaves are the major elements prone to burning, only these have been considered for estimating the energy generation in this study. It is, therefore, imperative to consider these crop residues primarily for energy generation to effectively tackle the issue of crop residue burning. The other residues generated from the harvesting and processing of rice and wheat crops, like husks and shells, are already being used for energy generation and allied purposes through established and regulated channels. The energy generation potential from these residues has, therefore, been eliminated in this study. The following table illustrates the power generation potential[2] from rice and wheat crops' field-based residues in the SAARC Member States.

Table 2: Power Generation Potential of SAARC Member States Using Rice and Wheat Farm Residues

Member State	Residue used	Total wheat & rice production (million Tons)	Gross Residue Production (million Tons)	Surplus Residue Production (million Tons)	Total Power Generation Potential (MW)
Afghanistan	Wheat straws	4.2	6.4	1.4	58
Bangladesh	Rice & wheat straws	38.1	57.2	15.6	1,100
India	Rice & wheat straws	212.6	319	80.3	5,395
Nepal	Rice & wheat straws	7.7	111.6	3	140

[2] Annual power generation potential = (Total Surplus residue in Tons) x (Collection Efficiency) / (365 x 24 x P)
Where P = Tons of biomass required to produce 1 MW of electricity

Member State	Residue used	Total wheat & rice production (million Tons)	Gross Residue Production (million Tons)	Surplus Residue Production (million Tons)	Total Power Generation Potential (MW)
Pakistan	Rice & wheat straws	36.3	54.4	13	834
Sri Lanka	Rice straws	2.4	3.5	1	71
Total		**301**	**452**	**114**	**7,598**

Different biomass conversion technologies like gasification, pyrolysis, and anaerobic digestion have been explored in this report for production of electricity, fuel by-products, biogas for cooking etc. The choice of technology is dependent on many factors like type, quantity and quality of agriculture feedstock, desired energy form, economic viability, by-products produced and environmental standards.

The sustainable operations of a biomass power plant are largely dependent on the cost of biomass, capital investment and operation and maintenance costs. Although the cost of generation using biomass as fuel is more than the existing prices of electricity using fossil fuels, the economic benefit to the farmers and environmental benefits counteracts the returns of fossil-fuel based energy generation.

Table 3: Comparison of Cost of Generation Using Biomass Energy Conversion Technologies

Particular	Combustion	Gasification	Pyrolysis	Anaerobic Digestion	Co-firing
Installation Cost (Avg)	1,035,000 USD/ MW	700,000 USD/ MW	900,000 USD/ MW	275 USD/unit	460,000 USD/MW
Cost of generation	0.134 – 0.14 USD/ kWh	0.12 – 0.13 USD/ kWh	0.13 – 0.14 USD/ kWh	Not Applicable	0.13 – 0.135 USD/ kWh
Existing grid prices			0.85 – 1.0 USD/kWh		

This report also studies some successful business cases and best practices at the global level for replication in the SAARC Member States.

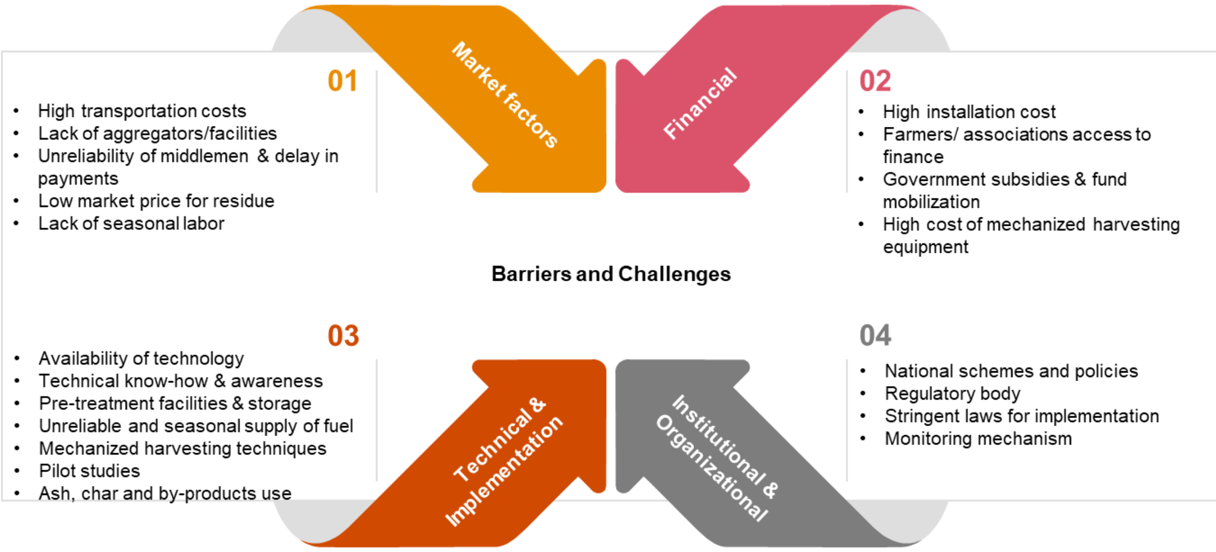
Since rice and wheat are the major contributors of the crop residue that is burnt every year in the SAARC Member States, it is recommended to implement biomass-based energy generation projects in the respective Member States focusing on farm-based residue.

In countries like India and Pakistan, where the Kharif and Rabi harvesting seasons are followed, it is recommended to install power projects with smaller capacities to operate on rice and wheat residues alternatively throughout the year. This will also ensure lower capital costs, land requirement and storage space for the residue.

Based on the country and region-wise production of agricultural crops the implementation strategy of different bioenergy programs, has been tailor-made for each Member State. The same can be viewed in Section 8.1.

Biomass-based energy generation technologies, face significant institutional and operational barriers in deployment due to difficulties in sourcing reliable and affordable supply of biomass. A review of the laws and policies of crop residue management in SAARC Member States has revealed similar barriers and challenges in successful deployment of energy generation projects across the region. The biggest challenge faced by countries is the lack of awareness in the farmers on the adverse effects of residue burning and the information on other sustainable uses of residue usage, which can aid in the economic development too. Another crucial challenge is the lack of stringent enforcement of penalties on perpetrators violating the ban on crop residue burning. Each of the SAARC Member States face similar barriers in deployment of biomass-based energy projects, albeit with varying intensities:

Figure 2: Barriers in Deployment of Biomass-Based Energy Projects in the SAARC Region



A broad list of recommendations for implementation and deployment energy generation programs using crop residue is also presented in this study. It is concluded that to successfully tackle the issue of crop residue burning in the SAARC nations, it is imperative to raise the farmers' awareness to the drawbacks of residue burning by increasing their knowledge and awareness on bioenergy programs through training and capacity building camps. These awareness programs will also need to be augmented by technical support and incentivizing mechanisms by the government, for both farmers and developers, to increase the penetration in the bioenergy market.

1 Introduction

1.1 Background

The SAARC Member States are agrarian countries wherein agricultural practices contribute to over 20% of their GDP and is a source of subsistence to over 60% of the population. Due to this large dependency on agriculture an enormous amount of agricultural residue is also produced each year. In countries such as India, Pakistan, and Bangladesh it is a common practice to grow 2-3 crops in rotation every year in the same field. The practice is most followed for rice and wheat farming in these countries. Due to very short window of time between harvesting of one crop and the sowing of the next, the farmers are left with a difficult decision to dispose the residues. While a small amount is used as cattle feed, manure, cooking fuel and bedding, around 80% of it is burnt in the fields. Generally, wheat and rice residues are burnt in the fields. The quantum of residue burnt in-situ in these countries is shown below.

Table 4: Crop Wise Residue Burnt in SAARC Countries in 2016 (Tons) (major crops only)

Country	Rice/paddy	Wheat	Maize	Sugarcane	Total
Afghanistan	65,450	920,084	151,900	866	1,138,300
Bangladesh	6,262,274	178,001	334,974	63,932	6,839,181
Bhutan	10,552	586	23,625	304	35,067
India	23,630,739	12,092,000	10,200,000	3,217,500	49,140,239
Maldives	NA	NA	32	NA	32
Nepal	749,600	298,329	891,583	52,605	1,992,117
Pakistan	1,521,057	3,657,239	1,334,000	735,033	7,247,329
Sri Lanka	578,277	NA	72,390	10,888	661,555

Source: FAO Statistics

Burning of these residues emits GHGs such as CO2, SO2, NO2, CH4 and N2O, which are responsible for raising global temperatures and creating a thick haze most noticeable in the Indo-Gangetic Plain. This pollution is the cause of poor visibility in the region and leads to accidents and health issues. Each year, several cities in India, Pakistan and Nepal are identified as the most polluted cities globally. GHGs are the biggest contributors to global warming and pollution which results in smog. The emission factors of the major contributors are shown below.

Table 5: Emission Factors of Major GHGs

Name of Gas	Emission factors of crop residues (g/kg)
Carbon Dioxide (CO_2)	1,515
Methane (CH_4)	2.7
Nitrous Oxide (N_2O)	0.07

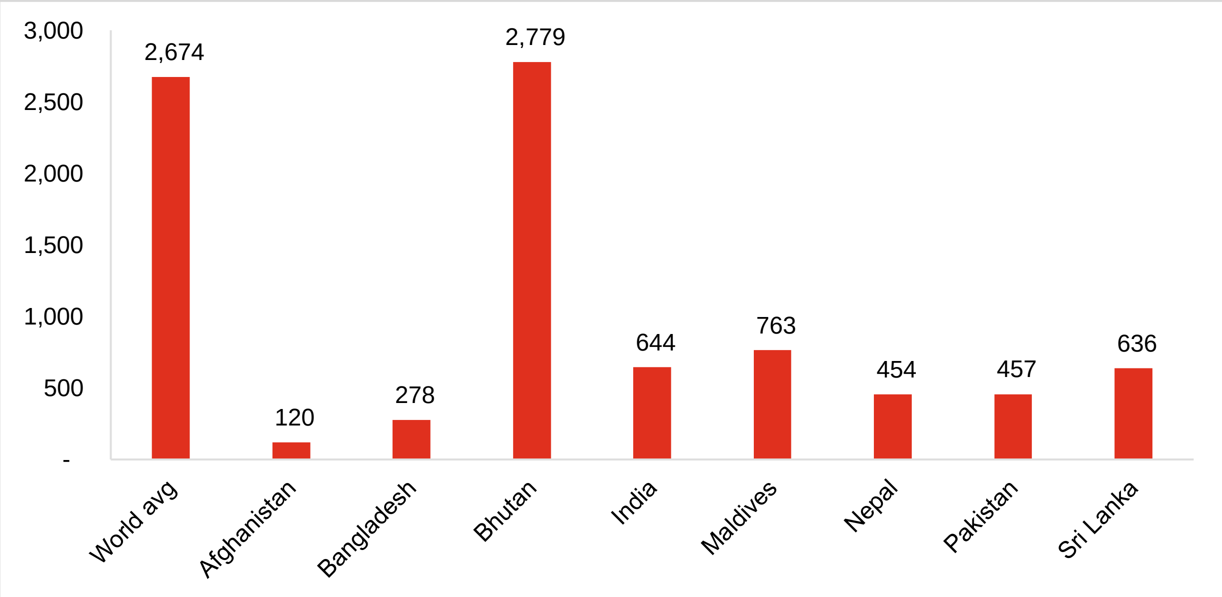
Source: International Science Congress Association

Given the surplus residue production of over 350 million Tons that is burnt each year in the SAARC countries, it is estimated that over 550 $MMtCO_2e$ and 1 $MMtCH_4e$ are released in the atmosphere.

This residue can be used for energy generation purposes to mitigate the enhancing greenhouse effect. Several bioenergy programs have been initiated in the SAARC countries to meet the rising energy demands of their growing economies. This, coupled with depleting conventional fuels and environmental concerns has put an impetus on exploring energy sources from other renewable and sustainable sources. The energy generated by using the agricultural residues can be used to bridge the demand-supply gap by providing electricity to rural areas, which are still not connected to the grid.

Energy plays a key role in the growth of any economy. Developed countries have reached their present standard of living by pursuing a path of energy-intensive industrial growth. With a rise in per capita incomes, upper middle-income countries have also witnessed a rise in per capita energy consumption. The per-capita energy consumption is low in the SAARC countries as compared to developed nations around the globe. For example, even though India accounts for roughly 18% of the world's population, it uses only around 6% of the world's primary energy. The per capita energy consumption for SAARC countries in comparison to the world average is depicted below:

Figure 3: Per Capita Energy Consumption (kWh/person/year)



Source: Sustainable Energy for All (SE4ALL) data catalog, World Bank

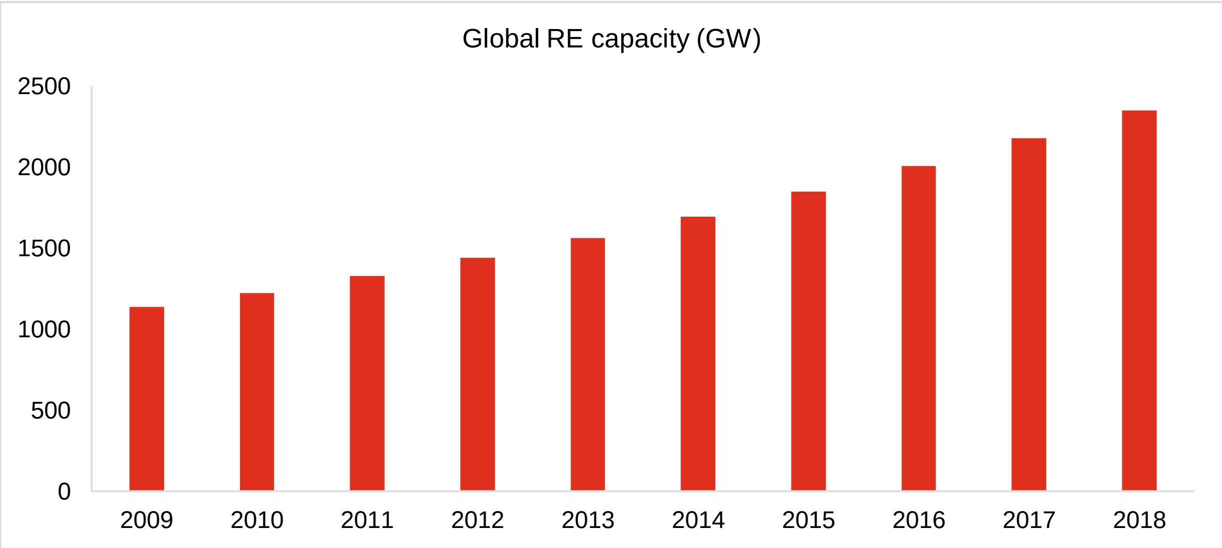
Developing economies are moving fast to ensure universal access to power. Every household will be connected to the grid and increasing standards of living enables such households to consume more energy. Global energy demand is poised to grow by ~30% by 2040, spread across all sectors of the economy. Industries and buildings would account for 75% of the increase in energy demand. This growth in energy demand is driven by developing economies with increasing population and prosperity, led by India and China.

The GDP growth in SAARC nations is pegged at 5-8% per annum till 2040. This growth is massively driven by a spike in productivity (GDP per head), pulling people out of the low-income status. Global energy trends will be shaped by this large, growing middle-class in the developing economies.

Industrial energy demand has been dominated by China in the past decade. However, the growth in Chinese industrial demand for energy is expected to peak in the mid-2020s with a decline thereafter. Industrial energy usage is expected to shift from China to the SAARC nations, other Asian and African countries, which are expected to account for a two-third share in industrial energy demand growth.

Renewable energy sources (including hydropower) currently make up almost 26% of the generation mix at a global level, increased rapidly since the year 2000. This growth has been driven mainly by ambitious climate change policies leading to the addition of new solar and wind capacity, led by the United States, China, European Union, India, Australia, and Japan. The sharp fall in RE development costs in recent years has also enabled developing countries to grow their renewable capacity base. The figure below depicts the steady growth of installed RE capacity around the globe and the current RE capacity installed in the SAARC Member States.

Figure 4: Global RE Installed Capacity (GW)



Source: IRENA, Renewable Capacity Statistics 2018

Table 6: RE Capacity Installed in SAARC Member States (as on Dec 2018)

Country	Installed RE Generation Capacity (MW)
Afghanistan	355
Bangladesh	568
Bhutan	1,615
India	117,919
Maldives	11
Nepal	1,112
Pakistan	13,049
Sri Lanka	2,091
Total	**136,720**

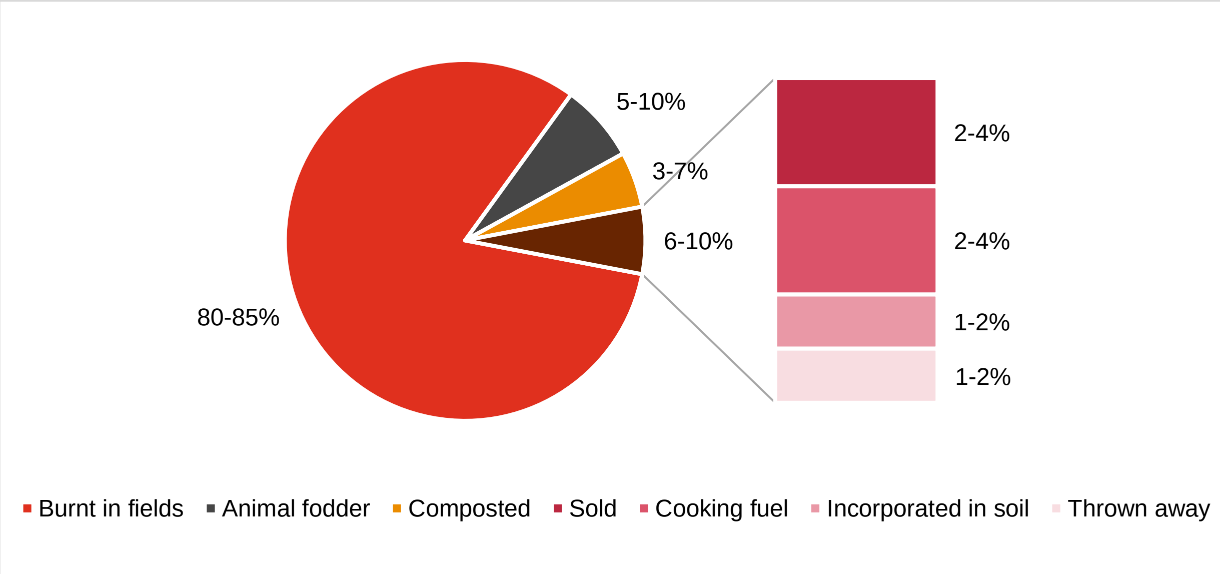
Source: Energy Statistics of each country

Renewable energy capacity additions in the SAARC countries can fulfill the increase in energy demand generated because of the increasing prosperity and population. However, biomass has still not been sufficiently explored as an energy generation source, since the focus has been on solar, wind and hydel energy. Crop residues can be a useful source of biomass energy generation but most crop residues are burnt leading to various disadvantages.

Crop residue burning

Out of various crops cultivated in the SAARC Member States, cash crops like rice, wheat and sugarcane are prone to crop residue burning. These crops are preferred by farmers for their higher economic returns, as compared to other crops. Rice-wheat cropping is commonly followed in SAARC countries, which leaves a very small window of 2-3 weeks between the harvesting of rice and preparing the farm for sowing of wheat. Harvesting of rice and wheat generates large volume of agricultural wastes, both on and off farm. As a result, the farmers prefer to burn the rice straw or stubble that is left behind after the harvesting of rice as the fastest and most economical method to prepare for the next crop. Alternatively, crop residues are used as bedding for animals, cattle feed, soil mulching, biogas generation, compost, thatching for rural homes' roofs, fuel for domestic and industrial use, and only a very small scale- biomass energy production. The graph below shows the most common ways the farmers deal with the crop residue disposal.

Figure 5: Disposal Methods of Crop Residue in SAARC Region



As shown above, majority of crop residue (80-85%) is burnt 'in-situ primarily to clean the field for timely sowing the next crop. The problem of in-situ burning of crop residues has intensified in recent years due to shortage of human labor, high hourly rentals of machines to remove the crop residue from the field and increased mechanized harvesting of crops that leave behind the crop stubbles. The burning of crop residue has many adverse effects as listed below:

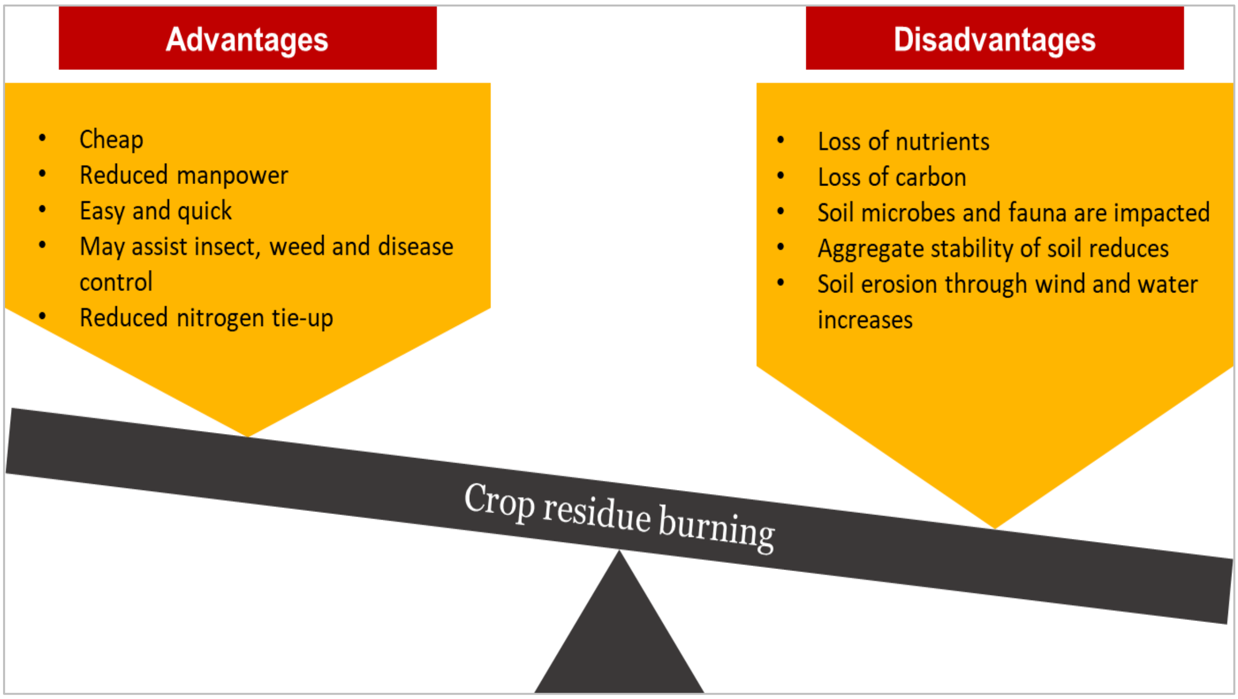
Greenhouse gas emissions: Crop residue burning is a source of Green House Gases (GHGs) and aerosols such as methane, carbon monoxide, nitrogen oxides and other hydrocarbons. This practice also emits huge amounts of particulates composed of a wide variety of inorganic and organic species. Each Tons of residue burnt releases 1.5 Tons of CO_2, 2.7 kg of CH_4 and smaller quantities of other GHGs into the atmosphere.

Accidents and health hazards: The smoke emitted by the burning of crop residue contributes to smog and leads to accidents due to low visibility, particularly in India and Pakistan. The smog also contains harmful GHGs, Particulate Matter and Black Carbon that are harmful to human health which may lead to various lung/air borne diseases. In the last year, air pollution has caused the death of over 1.2 million and 28,000 people in India and Pakistan respectively, and also affected million others with acute respiratory infections (ARI).

Soil health: Crop residue burning leads to the loss of nutrients. If the crop residue is incorporated or retained in the soil itself, it gets enriched, particularly with organic carbon and nitrogen. Frequent residue burning also leads to complete loss of microbes and reduces level of nitrogen and carbon in the top 0-15 cm soil profile, which is important for crop root development.

The pros and cons of crop residue burning have been summarized below, which clearly show the disadvantages of crop residue burning outweigh the advantages. The crop residue must be used to generate green energy in different forms, having the dual benefits of mitigating crop residue burning issues and reducing the power deficit.

Figure 6: Pros and Cons of Crop Residue Burning



Biomass has been identified as one of the thrust areas of renewable energy development in the SAARC nations for its abundance and economic value. Biomass resources are available in the form of wood, agricultural crops and residues, municipal solid waste, animal manure and human sewage. Of these, crop residues are available relatively uniformly in certain identified regions compared to other renewable resources in these countries. Although traditionally this residue has been used as cooking fuel in rural households, the rising demand for off-grid electricity and increased standard of living has led to exploration of energy generation from this biomass in many countries. Several biomass conversion technologies like gasification, pyrolysis, and anaerobic digestion are being explored for production of electricity, fuel by-products, biogas for cooking etc. The choice of technology is affected by many factors like type, quantity and quality of agriculture feedstock, desired energy form, economic viability, by-products produced and environmental standards. Hence, it is essential to determine the crop residue potential in individual countries to be used for energy generation, the technologies that can provide clean energy and any barriers in the development and deployment of such solutions.

1.2 Objective of the Study

Rice-wheat cropping system is dominant in the area constituting Pakistan, India, Bangladesh, and Nepal; resultantly, this area is producing enormous quantity of rice straw residues, which are generally burnt in open air. This has some short-term advantages to the farmers; however, it also results in health and environmental problems. The black carbon emissions from crop residue burning combines with dense winter fog and give rise to atmospheric smog in South Asia. This smog has serious negative health impacts, and leads to eye infections, coughing, headache, asthma, allergies etc. Smog is also particularly bad for cardiac patients. Therefore, to counter these environmental and health impacts, the open air burning of crops needs to be minimized.

SAARC Energy Centre conducted this study to evaluate other possible uses of the crop residues instead of open burning. There is good potential for use of crop residues (including rice), and the focus of this study is on the alternate uses for crop residues.

Assessment of alternate options for using crop residue instead of open burning in the fields. This includes technology options such as synthesis gas generated through gasification process and its uses.

Provide country-wise recommendations to policy makers, private sector, and small & medium enterprises (SMEs) on how to utilize crop residue to economically meet energy needs, tackling localized air pollution and for conserving environment.

1.3 Scope of the Study

Market research and benchmarking – Study of agriculture sector and major crops cultivated in SAARC Member States. The study covers seasonal availability of these crops, area of cultivation and volumes.

Study of disposal methods - The study estimates the major state-wise potential for residue utilization, the harvesting periods of various crops in each Member State and their current disposal method adopted: fodder, compost, burnt, sold etc. The second stage of this study covers the supply chain management from harvesting to utilization, storage methods to be used and weather effects on the crop residue.

Technology assessment – Assessment and evaluation of different technologies for crop residue usage, including, but not limited to, gasification to produce syngas, estimation of crop residue available and their energy generating potential. Cost benefit analysis and selection of viable business models for each Member State are ensured. The study also includes assessment of International best practices and success stories for replication.

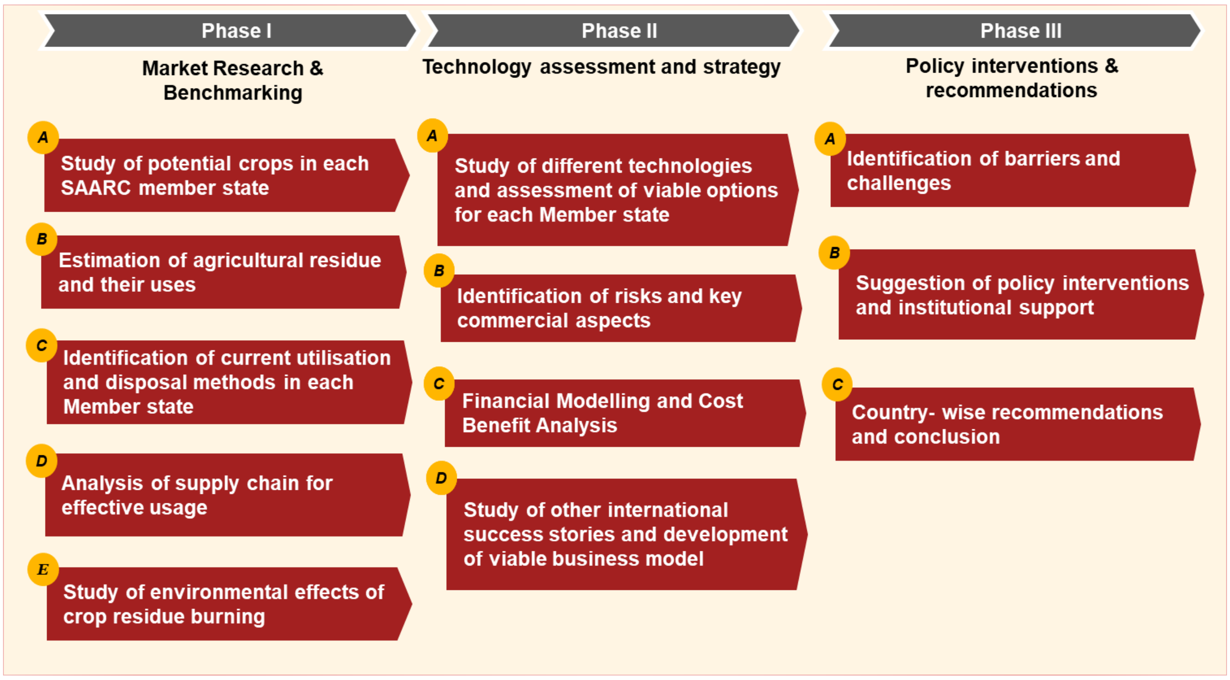
Study of environmental effects- The study includes the effects of localized air pollution in larger states and its effect on the weather. The effects of smog on human health and other external causes are also assessed.

Policy interventions and recommendations- Study of policies for effective management of crop residue in each Member State, the penalties and incentives imposed, and local government support. The study also examines the barriers and challenges in each Member State for effective dispersion of solutions. Thus, realistic policy interventions and recommendations for each Member State are provided for various stakeholders.

1.4 Methodology of the Study

The broad approach and methodology is outlined below:

Figure 7: Approach and Methodology of the Study



1.5 Limitations of the Study

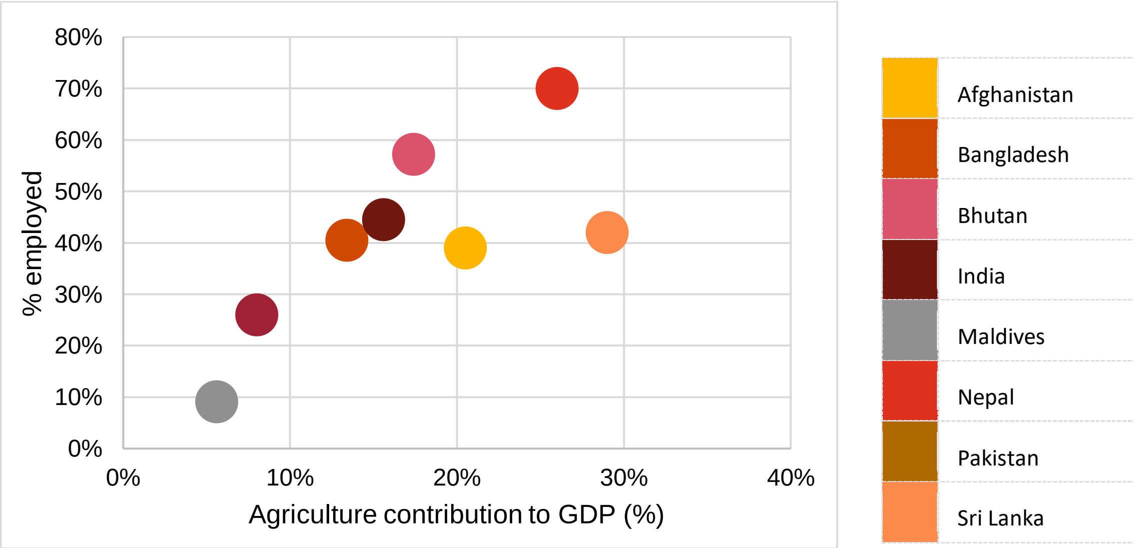
1. The analysis and data collection are based on public sources of information such industry studies, journals, publications and various research databases.
2. Analyses are based on the data/information/report shared by SEC relevant for the study.
3. The study undertaken is limited to secondary sources and discussion only and no primary research has been undertaken for the assignment.
4. During the course of analysis and benchmarking, widely acceptable norms are used, in case the actual information was unavailable.

2 Agriculture Residue Potential in SAARC Member States

2.1 Overview of Agriculture Sector

Over 65% of the population in SAARC region lives in rural areas, largely dependent on agriculture for their livelihood and sustenance. Although some of the economies in this region have witnessed rapid growth in the previous decade, yet agriculture remains the predominant occupation for 40-80% of the workforce. Sustained growth of agriculture sector is imperative for eradication of poverty, livelihood security, reduction in hunger and promotion of sustainable and inclusive growth of the regional economies. The table below shows a comparative study of the individual country's contribution from agricultural practices to the GDP and the percentage of workforce employed in such practices. Countries like Nepal and Sri Lanka have a larger share of workforce engaged in agricultural practices as compared to other countries, owing to their considerably small geographic areas and lower population.

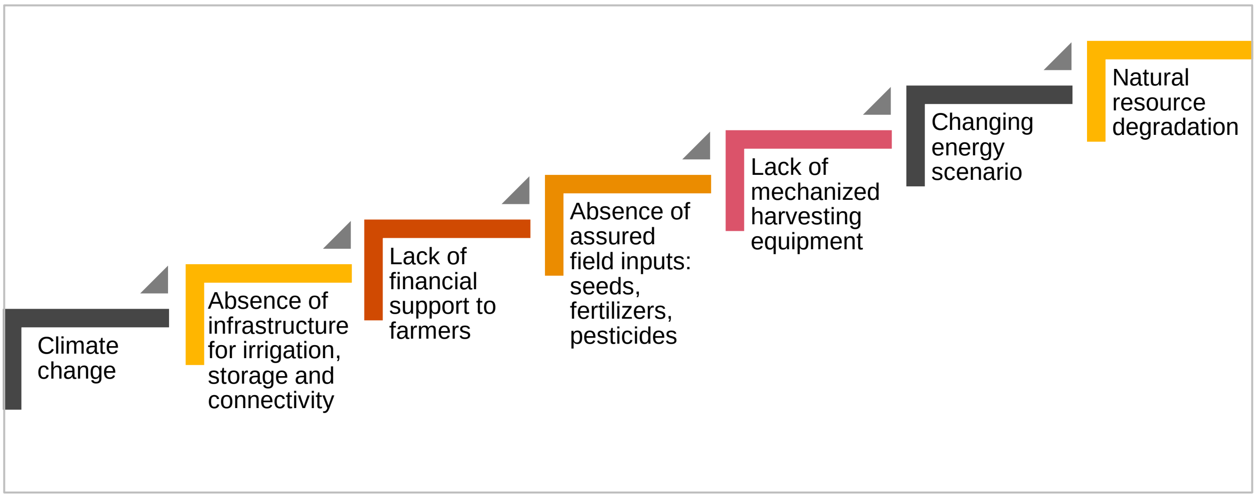
Figure 8: Agricultural GDP and Employment in SAARC Member States



Agriculture farming in South Asia is dominated by small fields, where average size of field is below 0.5 hectare in Bangladesh, and below 1.0 hectare in Sri Lanka and Nepal. In India, the average farm size is 1.4 hectare. Pakistan, however, endowed with land resources, fares better than others, with an average farm size of 3.0 hectare. Holdings below one hectare, accounts for more than 60% of total farm holdings in the SAARC region.

Due to low infrastructural developments, the agricultural activity in these countries is largely dependent on rain-fed farming. The agricultural irrigated land (percentage of total agricultural land) ranges from as low as 3% in Bhutan to 59% in Afghanistan. Other major common challenges faced by farmers in the SAARC region are shown below. The next section covers agricultural practices, overall crop production and agriculture governing bodies in each Member State.

Figure 9: Major Challenges in SAARC's Regional Agriculture



2.1.1 Agriculture Scenario in Member States

2.1.1.1 Afghanistan

In Afghanistan, around 82% of its total population lives in rural areas. Almost half of the rural population are dependent on farming business, which is their only source of income. In FY 2017, the country's agriculture sector (including fishery and forestry) contributed about USD 4 billion to the national GDP, representing a share of ~21%. Wheat and rice accounts to ~75% and 9% of the total crop production (5.5 million Tons). Despite its wheat production, the wheat imports grew significantly by 12%, to 3.7 million Tons in FY 2018 from 3.3 million Tons in FY 2017. The country has been relying on imported cerals to meet its population's dietary energy requirements.

Figure 10: Year-wise Agriculture GVA (USD bn)

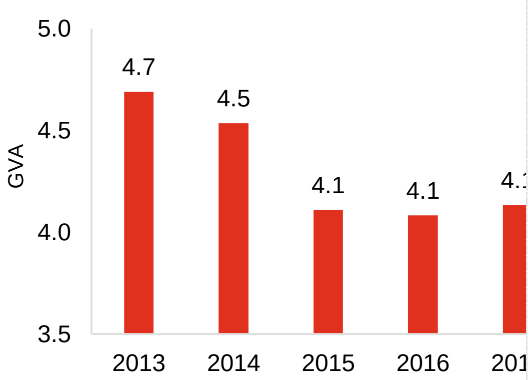
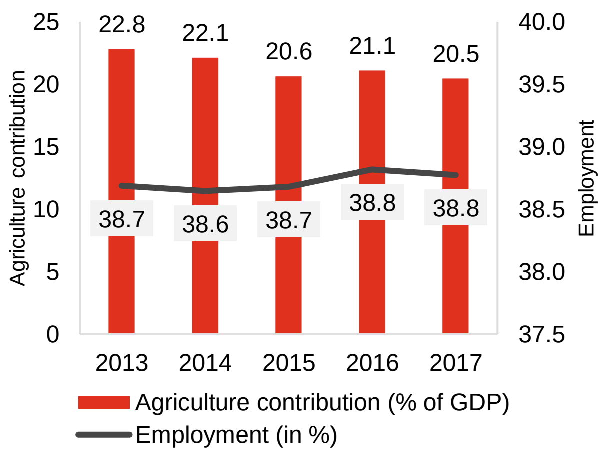


Figure 11: Year-wise Agriculture Contribution to GDP & Labor Employed in Agriculture Sector in Afghanistan



Source: World Bank

Except in 2017, where the agriculture GVA that includes fishery and forestry increased marginally by 1.2%, the agriculture GVA has decreased to a large extend in the preceding years. There are various reasons for such decrease, such as lack of access to affordable farming inputs, limited use of best agriculture practices, scarcity of water, lower rainfall, accumulation of snow pack during the winter which damages the crops, etc. which affects the country's agricultural yields to fall below the world average.

Figure 12: Total Crop Production (Total: 5.5 million Tons) in Afghanistan

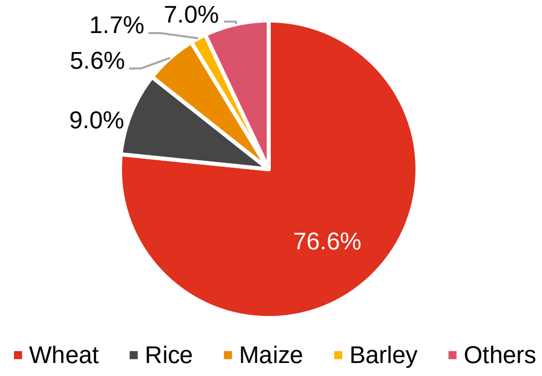
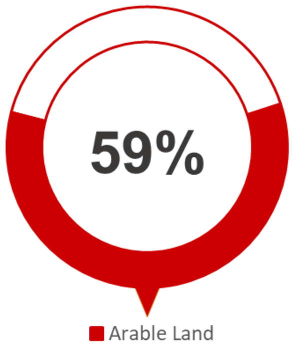


Figure 13: Arable Land in Afghanistan



Source: GIEWS Country Brief, Afghanistan, 2019

Out of the total arable land (59% of total land), the country has been able to utilize only 5.7% of total arable land. Under-utilization of land is one of the major reasons leading to high level of imports of agriculture products.

Despite various challenges, the country has been taking steps to improve the agricultural exports which grew at a CAGR of 35% during the period 2012-16. Amongst the total agriculture exports, cereals and edible fruits and nuts grew at a CAGR of more than 150% during the same period. The agriculture sector is governed by the Ministry of Agriculture, Irrigation and Livestock (MAIL), which is responsible for formulation of polices, educating the farms, implementation of projects undertaken by multilateral agencies, natural resource management, ensure food security, etc. In addition to this, MAIL plays a vital role to encourage and support the traders and producers of agriculture crops by linking them to international and domestic markets.

2.1.1.2 Bangladesh

Bangladesh, a country that covers an area of approx. 147,570 sqkm, is one of the agro-based developing countries in the world.

Figure 14: Year-wise agriculture GVA (USD bn)

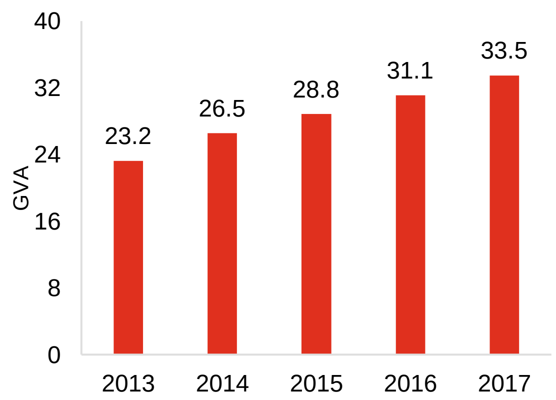
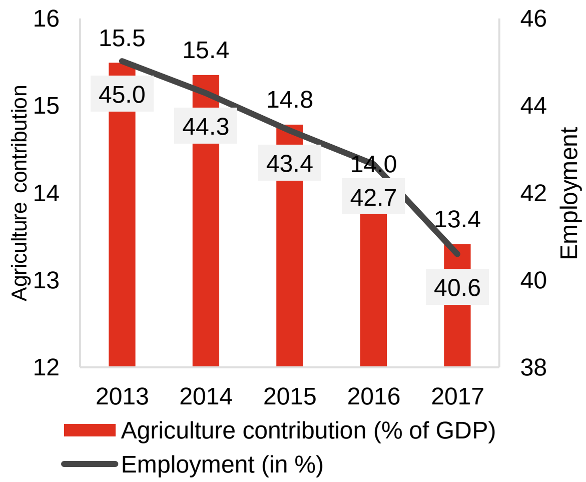


Figure 15: Year-wise Agriculture Contribution to GDP and Labor Employed Sector in Bangladesh



Source: World Bank

Agriculture has been the backbone of Bangladesh economy as it contributed to 13.4 % of the total GDP in FY2017 and employed more than 40% of the workforce in the agriculture sector during the same period. Like other developing nations, majority (~80%) of the rural population is heavily dependent on the agriculture sector for their livelihood. In the last five years, the country has witnessed a steady growth of agriculture sector. The agriculture GVA grew at a CAGR of ~10% to USD 33.5 billion in 2017 from USD 23.2 billion in 2013. Due to migration of the workforce towards other sectors especially textile sector, the workforce in the agriculture sector declined to 40.6% in 2017 from 45% in 2013.

Figure 16: Total Crop Production (Total: 81.4 million Tons) in Bangladesh

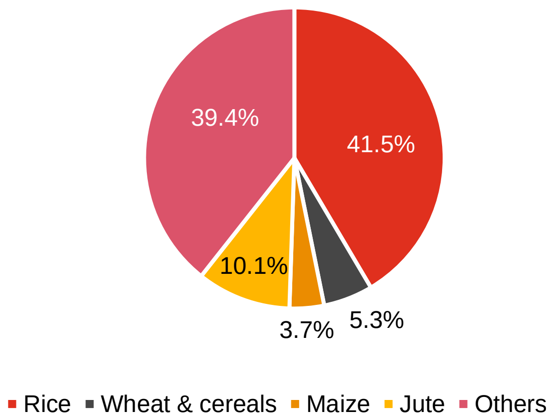


Figure 17: Total Arable Land in Bangladesh

Source: Bangladesh Grain and Annual Feed Report, 2018

As on 2016, Bangladesh had an arable land of 59.6%. However, due to rapid urbanization, the country is losing agriculture land at a rate of 1% per year, which may have significant impact on the agricultural crops production.

During the period 2013-17, the total exports of agriculture products declined at a CAGR of 3%. In the same period, exports of fiber which contribute to 61% of the total agriculture exports in 2017, declined at a CAGR of 6%. One of the reasons for decline in exports has been significant level of post-harvest losses, which are estimated to be 20-25% of total production. Lack of cold storage and efficient logistics system in the country are leading to high level of post-harvest losses, which results in huge losses to producers.

To overcome various challenges and ensuring long-term food security for the population in the country, Ministry of Agriculture has been tasked with implementation of projects and programs, which broadly covers creating awareness amongst the farmers, providing agricultural support and rehabilitation, developing irrigation infrastructure, storage and distribution centers, promoting modern cultivation method, etc. The government has taken initiative such as introduction of cards for fertilizers, seeds and other agricultural inputs, mechanization of irrigation and farming, diversification and marketing of crops and agricultural rehabilitation support to develop the agriculture sector.

2.1.1.3 Bhutan

Bhutan has undergone significant transformation in the last few years and has been engaging with the developing nation to develop its industry sector, which achieved impressive growth rate. However, Bhutan still relies heavily on imported food commodities such as vegetable, rice, fruits, sugar, etc. According to the labor force survey, approx. 57.2% of the total workforce is depending on agriculture for their livelihood. In 2017, the agriculture sector was the highest contributor to the national economy, followed by construction and hydropower sectors.

Figure 18: Year-wise Agriculture GVA (USD bn)

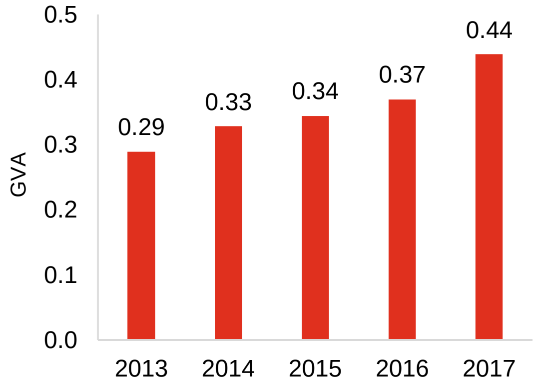
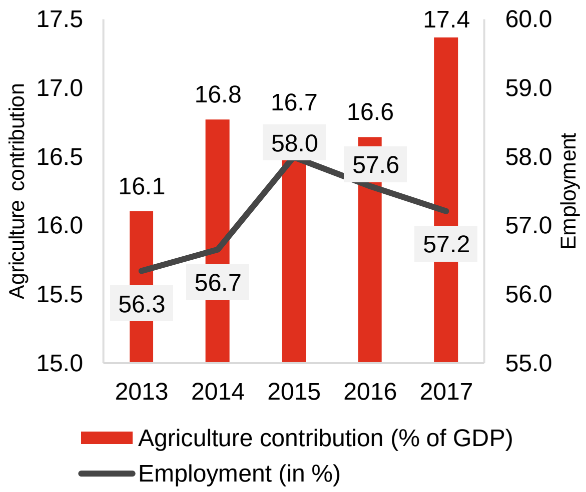


Figure 19: Year-wise Agriculture Contribution and Labor Employed in Agriculture Sector in Bhutan



Source: World Bank

In 2017, the agriculture GVA, which includes fishery and forestry, grew by 19% to USD 439 million from USD 369 million in 2016. In 2016-17, the total crop production stood to 0.38 million Tons, which includes 0.18 million Tons of vegetables and fruits. Due to large climatic variability across the different zones in the country, farmers are able cultivate almost all kinds of vegetable crops. Bhutan's major agricultural products include maize, rice, potatoes, milk, and species such cardamom, which is a profitable business in the country. Given the nature of landscape, which is almost 2,400 meters above the sea level, usage of tractors and other mechanized equipment is limited.

Figure 20: Total Crop Production (Total: 0.38 million Tons) in Bhutan

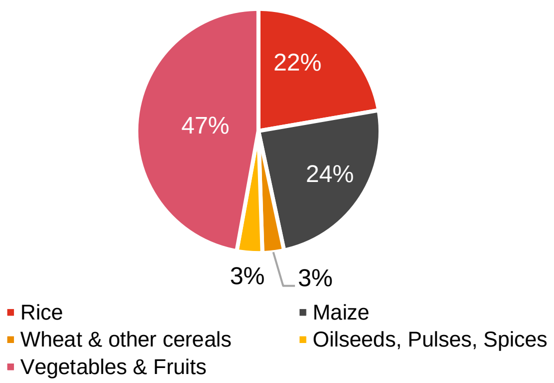
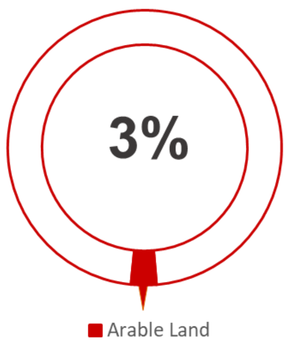


Figure 21: Total Arable Land in Bhutan



Source: Bhutan RNR Statistics, 2017

With only 2.6% of total land as arable land, the country is striving hard to achieve food self-sufficiency. During the period January-September 2018, the country imported rice worth USD 11 million and sugars worth USD 3.75 million. Bhutan imports food commodities majorly from India followed by imports from South Asian countries.

To support and govern the agribusiness, the Ministry of Agriculture and Forests (MoAF) has established different departments such as Department of Agriculture Marking and Cooperatives, Bhutan Agriculture and Food Regulatory Authority, Agriculture Machinery Centre, etc. In the 12th five-year plan, MoAF has set targets, which primarily focuses on enhancing national food self-sufficiency and nutritional security.

2.1.1.4 India

Agriculture is the primary source of livelihood of 44.5% of the total workforce. Gross Value Added by agriculture, fishery and forestry grew by 11.3%, to USD 414 billion in 2017 from USD 372 billion in 2016. India has been the largest producer, consumer and exporter of spices and related products and second largest fruit producer in the world. Total agricultural exports from India grew at a CAGR of 16.4% during the period 2010-18 to USD 38.21 billion in 2017-18. To boost the agriculture exports, the government has set up 60 agri export zones across the country.

Figure 22: Year-wise Agriculture GVA (USD bn)

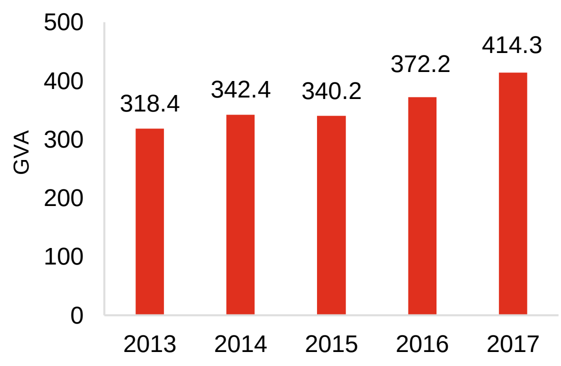
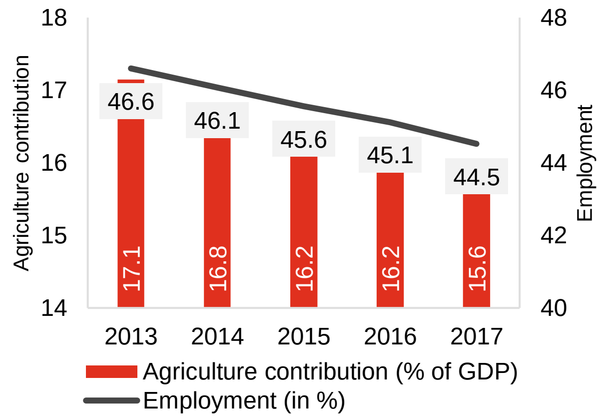


Figure 23: Year-wise Agriculture Contribution and Labor Employed in Agriculture Sector in India



Source: World Bank

Given the importance of agriculture sector, the government has undertaken serveral steps for its sustainable development. In 2016, the government has taken various steps to improve the soil fertilty through soil health card scehme, access to irrigation and enhanced water efficiency through the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), to support organic farming, to support creation of unified national agriculture market to boost the income of farmers and to mitigate risk in the agriculture sector through Pradhan Mantri Fasal Bima Yojana (PMFBY).

In 2017-18, the total food grain production stood at 284 million Tons, which is 9.7 million higher than the previous year's production of food grain. Sugarcane crops contributed to approx. 40% of the total crop production in 2017-18. During the same period, total production of rice increased marginally by ~3% to 112.9 million Tons from 109.7 million Tons in 2016-17.

Figure 24: Total Crop Production (Total: 744.3 million Tons) in India

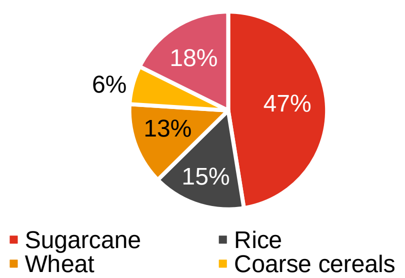
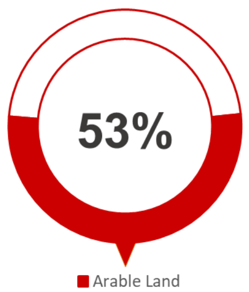


Figure 25: Total Arable Land in India



Source: Annual Report 2018, Department of Agriculture, Cooperation & Farmers Welfare

In 2016, arable land accounted to half of the country's total available land. Over the past few years, due to rapid urbanization, the land available for agriculture has been gradually reducing.

The Ministry of Agriculture and Farmers Welfare (MoAFW) is the apex body, which is responsible for formulating policies and administration of rules and regulations related to agriculture sector in India.

The ministry comprises of three departments, which oversees the programs and initiatives undertaken by the government. To eliminate the adverse effect of crop residue burning, MoAFW has formulated "National Policy for Management of Crop Residues (NPMCR)", which shall be adopted by various states. The objective of NPMCR is to control burning of crop residue, diversify the use of crop residue for various purposes, create awareness of ill-effects of crop residue burning and implement steps to curb burning of crop residue.

2.1.1.5 Maldives

The agriculture sector plays an important role in food and nutrition security; especially for people living in the rural areas. Maldives economy is dominated by two sectors i.e. tourism and fishing. Due to lack of availabiltiy of land for cultivation of crops, less fertile soil, shortages of fresh water, the agriculture development is limited in Maldives. As a result, the agriculture sector accounted for 5.5% of Maldives' GDP in 2017 and employed only 9% of the total workforce in Maldives.

Figure 26: Year-wise Agriculture GVA (USD bn)

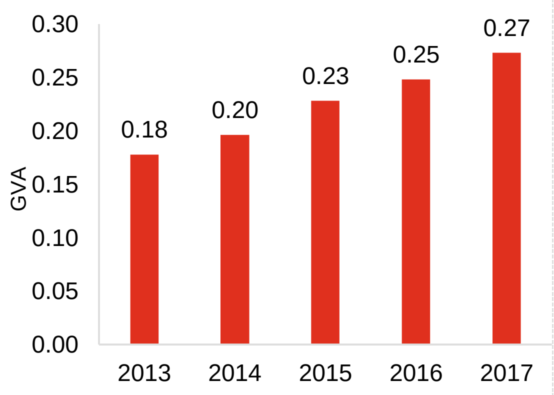
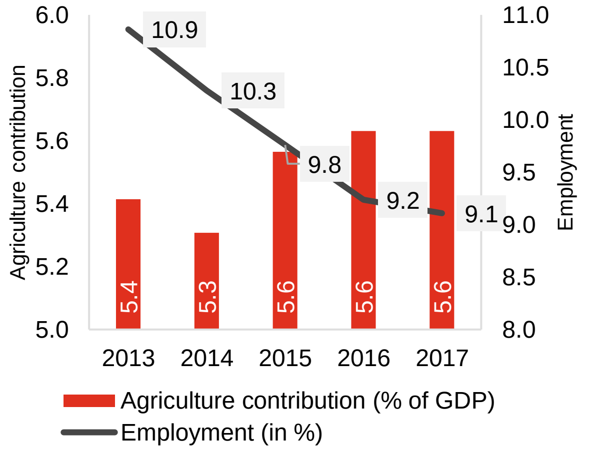


Figure 27: Year-wise Agriculture Contribution and Labor Employed in Agriculture Sector in Maldives



Source: World Bank

Figure 28: Total Arable Land in Maldives

Except for coconut and fresh fish, more than 90% of food items including stables are imported from neighbouring countries. Lack of storage facilities and heavy dependence on imports of food items, have posed a severe food security risks in the country. Of the total available land, only 13% of the land is available to carry out agriculture acitvity. And about half the arable land is in the form agriculture islands, which are leased by private players for agriculture development. In many islands, field crops such as potatoes bananas, papaya, pineapple, chillies, cabbage, pumkin are grown throughout the year.

While seasonal crops such mango, drumstick, etc. are high value crops, which contributes significantly to the income of a farmer.

Under the "Agriculture Development Master Plan for Sustainable Food Security, Agriculture and Rural Development", the government aims to improve and support small-scale farming, which can be carried out agriculture island. In Maldives, Ministry of Fisheries and Agriculture (MoFA) is responsible for the development of agriculture sector.

2.1.1.6 Nepal

Nepal is an agricultural country having 70% of the total employment directly engaged in the farming activities. While rice, maize, millet, barley are the major staple food crops, oilseeds, potato, sugarcane and jute are some of the important cash crops. Due to uncertain climatic conditions, most of the famers prefer to grow diversified crops. In addition to pulse crops and spices, Nepal grows several vegetable and fruits crops which include apple, peach, pear, lemon, mango, banana and cucumber, etc.

Figure 29: Year-wise Agriculture GVA (USD bn)

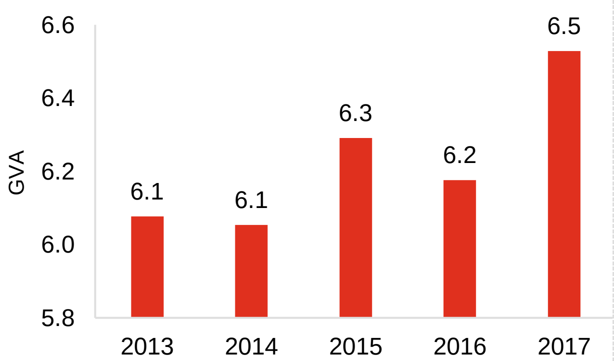
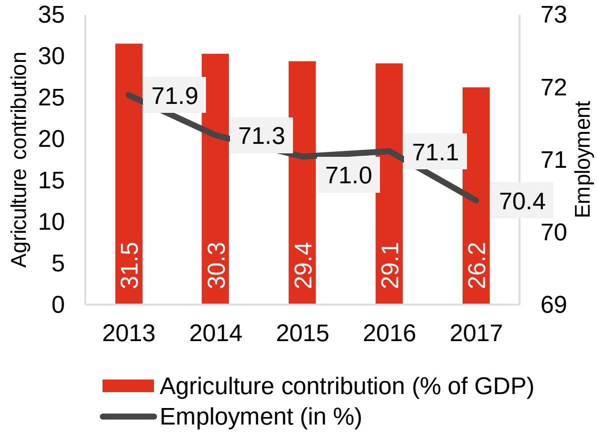


Figure 30: Year-wise Agriculture Contribution and Labor Employed in Agriculture Sector in Nepal



Source: World Bank

Agriculture sector contribute to a third of the total GDP of Nepal. However, the Gross Value Added has marginally increased to USD 6.5 billion in 2017 from USD 6.1 billion in 2013. Previously, the government has taken initiatives to improve the agriculture production but had minimal success. Despite having multiple sources of water, the country lacks efficient irrigation systems. In hilly terrains, transportation of goods has been also a major issue, which has adverse effects on the exports of agriculture products.

Figure 31: Total Crop Production (Total: 17.1 million Tons) in Nepal

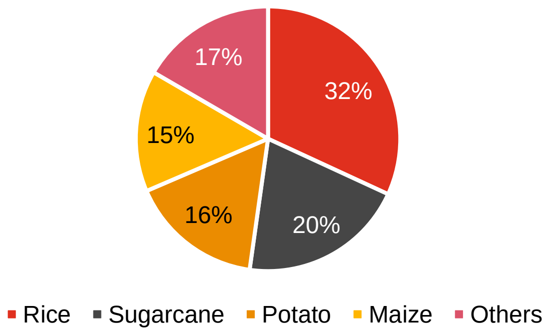


Figure 32: Total Arable Land in Nepal

Source: Nepal Statistical Yearbook

Nepal has only 17% of total land for the agriculture production. In the last nine years, the country's reliance on other countries for import agriculture products has increased by almost five times.

In 2017, Nepal's agricultural goods import crossed USD 1.7 billion, which includes cereals, vegetable fats and oil and vegetables worth USD 0.4 billion, USD 0.3 billion and USD 0.2 billion respectively.

Ministry of Agriculture and Livestock Development (MoAD) is a government body, which is responsible for the development and the growth of agriculture sector in Nepal. In 2014, MoAF has developed Agriculture Development Strategy (ADS), which aims to guide the agriculture sector of Nepal over the next 20 years.

Long-term targets of ADS include reducing the amount of degraded land by almost 50%, achieving 0 – 5 % in trade surplus (food grains), increasing agricultural exports to over USD 2 billion, increasing the agricultural land productivity by three folds to USD 4,787 in 20 years, etc.

2.1.1.7 Pakistan

Pakistan's agriculture sector plays a vital role in the economy as it contributed 22% of the total GDP in 2017 and absorbed 42% of the total workforce. The country's population is growing at a rate of 2.4% annually and this rapid increase in population is raising demand for agriculture products. The government has been taking steps to diversify crop production, promote high value crops, efficient use of water, enhance agriculture credits, provide electricity at subsidized rates etc.

Figure 33: Year-wise Agriculture GVA (USD bn)

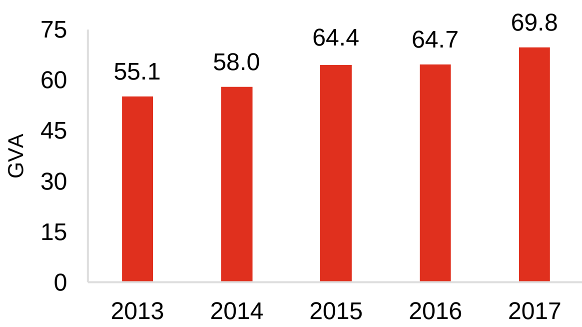
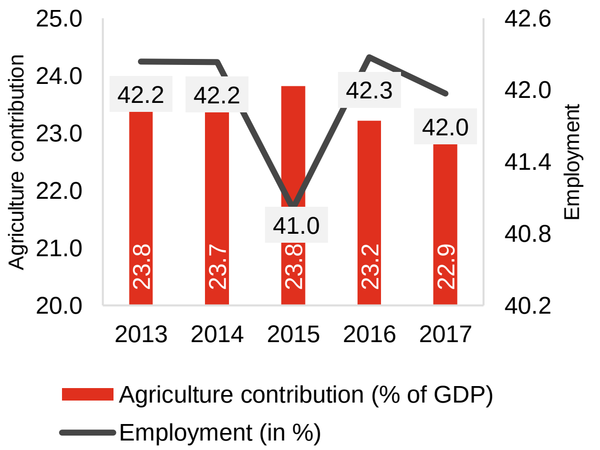


Figure 34: Year-wise Agriculture Contribution and Labor Employed in Agriculture Sector in Pakistan



Source: World Bank

In 2017, agriculture Gross Value Added grew by 7.9%, to USD 70 billion from USD 64.7 billion. During the same fiscal year, the crops sector performed well and witnessed a growth of 0.91 % against decline in growth rate by 5.2% in 2016. Sugarcane is a high value crop of Pakistan and is the raw material for sugar related industries, which is the backbone of the country's economy. Sugarcane contributes to approx. 63% of the total crop production in Pakistan.

Figure 35: Total Crop Production (Total: 129 million Tons) in Pakistan

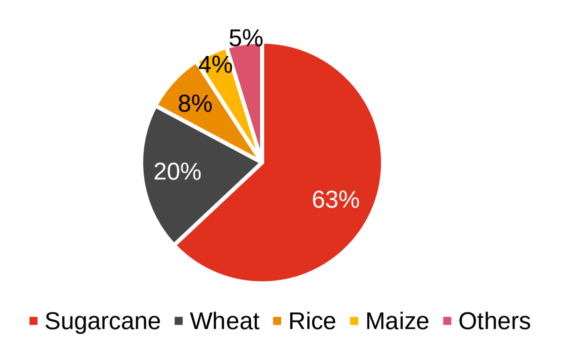
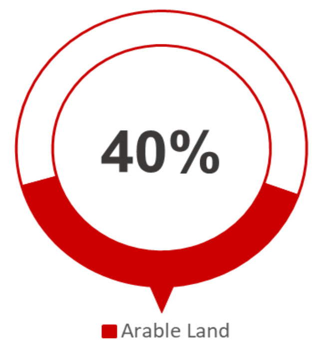


Figure 36: Total Arable Land in Pakistan



Source: Pakistan Economic Survey 2017-18

Agriculture land accounts to 40.2% of the total available land in Pakistan. During the period 2010-16, the total arable land increased marginally by ~2% from 38.1%.

Pakistan, like India, has two cropping seasons, Kharif and Rabi. The Kharif being the first sowing season starts from April-June and is harvested in during the period October-December. Rabi, which is the second sowing season starts in October-December and is harvested in April-June. Due to lack of efficient irrigation system, the agriculture sector in the country is heavily dependent upon the timely availability of water. In 2017-18, the availability of water in kharif and rabi season decreased by 2% and 18.5% respectively.

Ministry of National Food Security & Research (MoNFS), which is also known as Ministry of Agriculture is responsible for formulating, developing and executing policies related to agriculture sector. One of the focus areas for the Ministry has been production and promotion of compost from city-waste, crop residue and animal manure for production of fruits and vegetables.

2.1.1.8 Sri Lanka

Sri Lanka is blessed with fertile tropical land with a large potential to cultivate and process variety of crops. But, issues pertaining to productivity and profitabilty have hampered the growth of the sector. The agriculture sector contributed to 7.7% of the total GDP and employs close to a fifth of the total workforce. As rice is the stable food in the country, rice production accounts to 73% of the total crop production in Sri Lanka.

Figure 37: Year-wise Agriculture GVA (USD bn)

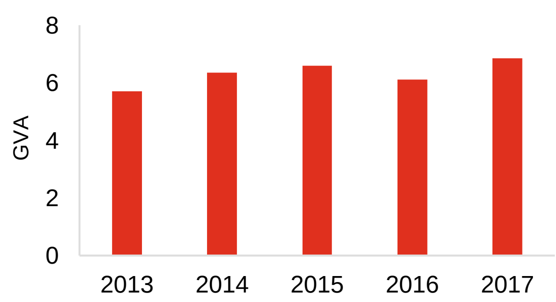
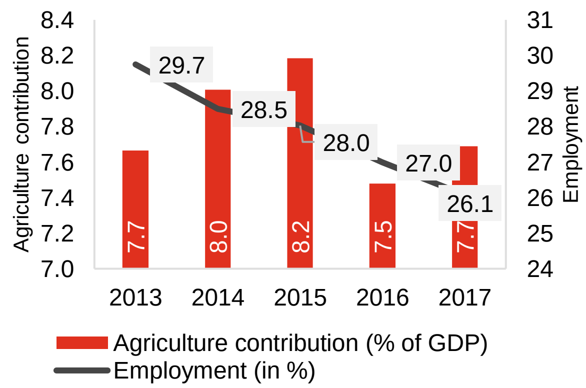


Figure 38: Year-wise Agriculture Contribution and Labor Employed in Agriculture Sector in Sri Lanka



Source: World Bank

In 2018, the import of food and beverages accounted for 7.2% of the total imports. In the same period, Sri Lanka imported 1.3 million Tons of wheat majorly from Canada and USA. In addition to this, imports of red lentils stood to USD 79 million in 2018.

Figure 39: Total Crop Production (Total: 3 million Tons) in Sri Lanka

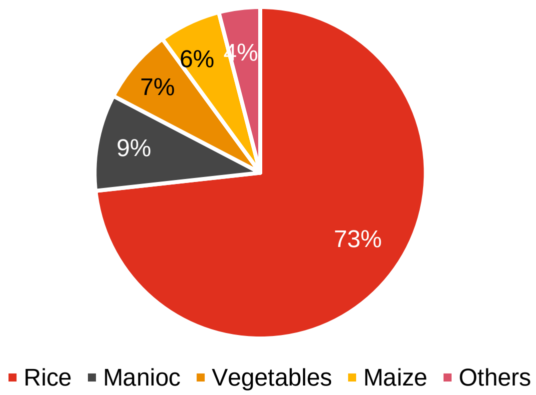
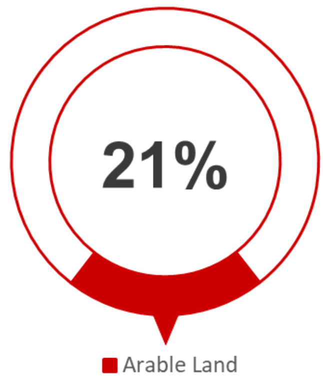


Figure 40: Total Arable Land in Sri Lanka



Source: Economic and Social Statistics of Sri Lanka, 2018

Agriculture land accounts to 20% of the total available land in the country. Unlike other countries, where the availability of arable land is in the decreasing trend, arable land in Sri Lanka has increased by ~4%, from 16% in 2007 to 20.7% in 2017. Almost two third of the arable land is in the dry zone, where bulk irrigation infrastructure is located. Majority of the farmers cultivate both rice and other food crops such as pulses, fruits, vegetables, cereals, etc.

The agriculture sector in Sri Lanka imposes various challenges such as low-level mechanization, high post-harvest losses, high transaction cost, lack of soil fertility management and limited agro-based industries, etc. To overcome these challenges, the government has identified e-solutions such as e-market place for agriculture, e-pest surveillance system, smart water management, real-time data system to monitor food crop production, early warning system, etc.

Ministry of Agriculture (MoA) is responsible for formulation and implementation of national policy. At the same time, provide necessary guidance for sustainable development of agriculture sector in Sri Lanka. MoA has recently drafted the "Overarching Agriculture Policy, 2019", which aims to enhance agriculture and Agri business through sustainable technologies and constructive partnership.

2.2 Potential Crops for Energy Generation in SAARC Member States

2.2.1 Potential Crops for Energy Generation

The potential crops for energy generation have been selected using a combination of factors like:

1. Area under cultivation
2. Annual production of crop
3. Estimated residue potential and surplus residue
4. Energy content of residue

As a thumb rule, the crops with the highest production in each Member State have been selected for energy generation. It is observed that cereals have the highest residue producing potential amongst all crops like pulses, oilseeds, cotton and jute. Cereal stalks and straws are also the prime residue that are subjected to crop residue burning. The potential crops in each country have been enlisted below:

Table 7: Potential Crops for Energy Generation in SAARC Member States

Afghanistan	Wheat, barley, rice, maize, potato, sugarcane, sugarbeet and cotton
Bangladesh	Rice (boro, aman and aus), wheat, jute, sugarcane and maize
Bhutan	Rice, maize, wheat and barley
India	Rice, wheat, maize, cotton, jute and mesta and sugarcane
Nepal	Rice, wheat and barley
Pakistan	Rice, wheat, maize, cotton and sugarcane
Sri Lanka	Rice and maize

Most of the residues from these crops are not available throughout the year but are accessible only at the time of harvest. This makes collection convenient, but on the other hand, creates storage related problems, if the residues have to be conserved for use during lean period. In India, normally two crop seasons, i.e., kharif and rabi are taken into consideration. Therefore, availability of crop residues is expected to be spread evenly over the year. As a result, crop residues of one kind or the other are available throughout the year.

It is imperative to consider the harvesting seasons of these crops to estimate the annual crop residue that will be available for energy generation. The table below provides a brief of the harvesting seasons in each of the Member States.

Table 8: Harvesting Patterns of Crops in SAARC Region

Country	Kharif-1 (March-June)	Kharif-2 (July-October)	Rabi (October-March)	Throughout the year
Afghanistan	100% of the winter wheat and barley are harvested in this period Rice is sown towards the end of this period	100% of the spring wheat and maize are harvested in this period	Rice is harvested in this period	None
Bangladesh	About 9% of the rice and 100% of the jute, sugarcane and groundnut are sown in this period. 100% of wheat, millet and pulses are harvested in this period	About 41% of the rice, and almost 100% of the maize are grown in this period Aus rice and jute are harvested during this period	50% of the rice and almost 100% of the wheat, pulses, millet, and potato are grown in this period. Rice, jute, sugarcane and groundnut are harvested during this period	Rice, coconut, vegetables etc.
Bhutan	Rice and maize are sown in this period Wheat and barley are harvested during this period	50% rice and 100% maize are harvested during this period	Wheat and barley are sown during the beginning of this period	None
India	About 7% of the Rice and 100% of the Jute, sugarcane and	About 84% of the rice, 100% of the maize are sown in this period	9% of Rice, and almost 100% of wheat, pulses and	Some amounts of rice, pulses and oilseeds

Country	Kharif-1 (March-June)	Kharif-2 (July-October)	Rabi (October-March)	Throughout the year
	groundnut are sown in this period. 90% of wheat, cotton and pulses are harvested in this period	10% of wheat and pulses along with jute and some maizes are harvested in this period	millets are sown in this period Rice, sugarcane and maize are harvested during this period	
Nepal	Wheat is harvested during this period Maize is sown during this period	Rice is sown during this period	Rice is harvested during this period	None
Pakistan	Rice, sugarcane, cotton, maize and millet are sown during this period		Rice, sugarcane, cotton, maize and millet are harvested during this period	Some amounts of rice, pulses and oilseeds
Sri Lanka	Rice and maize are harvested during this period		Rice and maize are sown during this period	Rice

2.3 Present Utilization and Supply Chain

2.3.1 Present Utilization AND Disposal Practices OF Crop Residue in Member States

Agricultural residues can be classified as those portions of the crop that cannot be consumed as food. These include leaves, husks, stalk, straw, stubbles and pods of seeds. Farmers usually rely on conventional ways for disposal of these residues by using them as animal food, fertilizers, in harvesting of other crops by ploughing them into the ground or burning them completely. However, lately, newer methods of utilization and disposal of these crop residues are being adopted. These include converting them into biofuels and composting. Such methods seem to be promising, but these have not been fully developed at large scale yet.

2.3.1.1 Utilization Practices

The waste generated from the agricultural sector can be favorably utilized in different agro-based applications and industrial processing. Different countries have different methods of utilization of the agricultural residues generated. Depending on their end use, the residues are processed while some are used in their raw form. The possible options include its use as animal food, composting, production of bioenergy and deployment in other extended agricultural activities such as mushroom cultivation. Many countries such as India China, Nepal, Indonesia, Japan, Thailand, Malaysia, Nigeria and Philippines use their crop residues to generate bio energy.

Table 9: Utilization Practices Adopted by SAARC Member States

Country	Use of residue
Afghanistan	Animal feed
	On farm applications
	Construction material
	Cooking
Bangladesh	Animal feed and bedding
	Tillage for organic fertilizer

Country	Use of residue
Bhutan	Mulching
	Cooking fuel
	Fuel wood
	Animal feed
India	Animal feed
	Biomass-based energy generation plants (in some regions)
	Paper and Pulp Board Production
	Mushroom cultivation
	Straw mulching
	Preparation of bio enriched compost/vermin compost and its utilization as farm manure
Maldives	Animal feed
	Cooking fuel
	Compost
Nepal	Animal feed
	Cooking fuel
	Compost
Pakistan	Animal feed
	Biomass-based energy generation plants (in some regions)
Sri Lanka	Paddy straw is used in the paper industry
	Biomass-based energy generation plants (in some regions)
	Making compost and fertilizers
	Cereal straw is used for building thatched roofs and used as packing material.
	Mulching
	Organic fertilizers

2.3.1.2 Disposal Methods

Burning is the most common disposal technique adopted by the farmers for disposal of residue. As previously stated, majority of the population belonging to the agricultural sector in the SAARC region lie in the low-income bracket. Usually, the farmers have a 20-day window to manage the crop residues before the sowing of the next crop. Traditional, as well as mechanized harvesting leaves residue in the fields in the form of stalks, stubble and straws that farmers burn to clear the field for sowing the next crop. Most farmers prefer burning of crop residue over alternate usage, as it is a quicker and cheaper option, and kill weeds and pests in the process.

Major reasons for burning the residue as disposal are stated below:

- Residues, having low nutrient content, and are not suitable for cattle fodder
- High rent of rotavator for mulching; for example, in India, it is INR 1,000 per hour (~USD 14/hour)
- Lack of manpower and high labor cost for efficient straw cutting since the introduction of mechanized farming
- Lack of storage space for residue, if collected
- Lack of adequate incentives for sale of such residue
- Burning is the cheapest disposal method

2.3.2 Present Storage Methods of Crop Residue

Although most farmers prefer the burning of residue as compared to other alternate usages, there is still a marginal number of farmers who store this residue for future use. In most cases, the residue is used as fodder for cattle or for making manure and fertilizers. The residue stored for self-use generally finds storage space inside the farmers houses, sheds or by the side of fields. In some cases, the residue is also bundled in bales and stored on top of trees or houses to keep them out of reach of cattle. Such storage is done at a domestic level and does not use any extravagant methods, like temperature and moisture control, making them prone to weather-caused degradation and excess drying or decomposition.

When the residue is sold to power plant developers, it is aggregated at the collection terminals, which have the facility to store large amount of residue for longer durations under atmospheric controlled conditions. This residue lasts longer and will be stored at the collection terminals till transferred to the power plant for energy generation.

3 Prevalent Disposal Methods

3.1 Present Disposal Methods OF Crop Residue in Member States

3.1.1 Potential Areas/States for Focus of Study in Each Member State

Most crop production in the SAARC countries is concentrated in irrigable land, rainfed areas and majorly across the Indo-Gangetic plains in India. For the purpose of this study, it is assumed that the regions with the highest production of major crops are the ones responsible for the highest quantity of crop residue generation. These areas are listed below for each of the SAARC countries.

Figure 41: Areas with Maximum Crop Residue in the SAARC states

Afghanistan	Bangladesh	Bhutan	India	Nepal	Pakistan	Sri Lanka
• Balkh • Baglan • Helmand • Herat • Kunduz • Nangarhar • Faryab	• Rangpur • Khulna • Rajshahi • Dhaka • Sylhet	• Wangdue • Punakha • Lhuntse • Trashigang • Mongar	• Uttar Pradesh • Punjab • Haryana • Maharahtra • Madhya Pradesh • Bihar	• Dhanusha • Sarlahi • Rautahat • Bara • Parsa • Nuwakot • Jhapa • Morang	• Punjab • Sindh • Khyber Pakhtun-khwa	• Mahaweli • Ampara • Polonna-ruwa • Batticaloa

3.1.2 Estimated Area Wise Potential in Focus Areas and Harvesting Season in Member States

While estimating residue potential in Member States, the important factors to be considered are type of residue (straw, husk, stalk, cobs, leaves, etc.) and their respective Residue Production Ratio (RPR). The RPR of each crop varies based on the crop group they belong to - cereal, oilseed, pulses, horticulture, sugarcane, etc. The RPR is the measure of the amount of residue left behind after the harvesting of a particular crop and can be defined as the ratio of mass of unused crop residue that is left after harvesting a particular crop to the mass of crop produced. The RPR is very high in case of cereals where the grains constitute a very small portion of the crop stalk. The RPR is low in case of crops like sugarcane, where the cane itself is the entire usable portion and the leaves constitute a very small portion of the crop.

However, for bioenergy generation the Surplus Residue Potential (SRP) is considered, which is the residue left after any competing uses (such as cattle feed, animal bedding, heating and cooking fuel, organic fertilizer). The Residue Production Ratio and Surplus Production Ratio of major crops grown in the SAARC region is indicated in Figure 42. These ratios have been used for deriving the Surplus Residue Potential across the Member States.

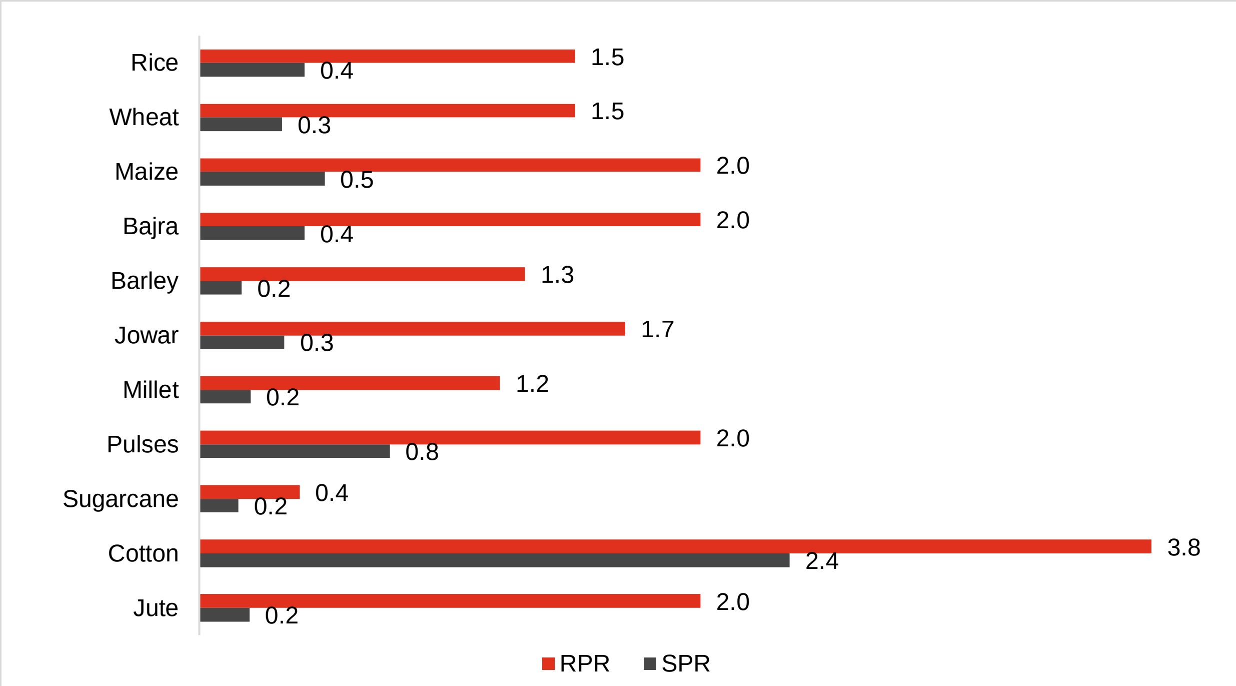
Methodology for deriving gross residue potential and surplus residue potential:

The Gross Residue Potential (GRP) is the total amount of residue produced after the harvesting of a crop, while Surplus Residue Potential (SRP) is the residue left after any competing uses. This surplus residue can then be used towards energy generation projects. The GRP is derived as a product of the yield of the crop with its respective RPR. The SRP of a crop is derived by multiplying the GRP with the Surplus Production Ratio of the respective crop as illustrated in Figure 42.

GRP = Yield of crop x Residue Production Ratio of the crop

SRP = GRP x Surplus Production Ratio of the crop

Figure 42: Residue Production Ratio and Surplus Production Ratio of Major Crops in Saarc Region



Source: ScienceDirect, Bioenergy potential from crop residue biomass in India

3.1.2.1 Afghanistan

Most of the crop production in Afghanistan is concentrated in the Northern region having access to irrigable lands and adequate rainfall. Wheat is the staple crop of Afghanistan and accounts for ~80% of the total cereal production, followed by rice, maize, and barley. Apart from cereals, various pulses, vegetables, and sugarcane are cultivated for domestic consumption. However, they account for only 7% of the total food production of Afghanistan and the country relies heavily on imports and aids for sustenance.

Table 10: Crop Residue Potential in 2016-17 in Afghanistan

Crop	Annual Production (000 Tons)	Gross Residue generated (000 Tons)	Surplus Residue Potential (000 Tons)
Wheat	4,280	7,704	1,695
Rice	505	859	240
Maize	315	725	180
Barley	95	124	16
Others (Potato, Sugarbeet, Sugarcane, Cotton)	392	274	104
Total	**5,587**	**9,685**	**2,235**
Energy Production (wheat straws only)	**4,280**	**6,420**	**1,412**

Source: GIEWS Country Brief, Afghanistan, 2019

Pulses and vegetables contribute to only 7% of the total food production and are cultivated in decentralized areas under favorable weather conditions only and as such their harvest is not reliable. For the purpose of this study, we have only considered residue production from wheat to address the issue of in-situ crop residue burning. Furthermore, only the residue that is burnt in the farms- like straws and stalks have been considered for deriving the surplus residue potential.

The gross residue generated from wheat straws/stalks is 6.4 million Tons, of which 1.4 million Tons is the Surplus Potential derived from straws and stalks that can be used towards energy generation.

Zonal distribution of total residue produced:

In Afghanistan, the leading provinces for residue production from cereal crops are Takhar, Baghlan, Faryab, Balkh, Kunduz, Herat and few areas of Helmand, Nangarhar and Ghazni. Most of these provinces lie on the Northern border of the country and allow for easy aggregation of surplus residues for energy generation.

Figure 43: Zonal Distribution of Total Residue Produced in Afghanistan

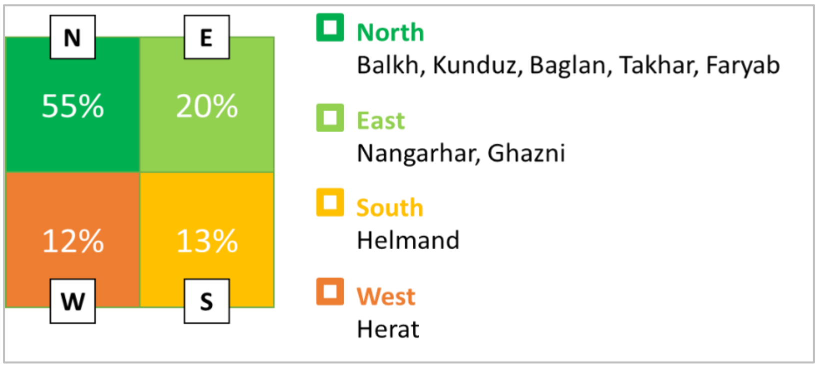


Table 11: Crop Harvesting Seasons in Afghanistan

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wheat & Barley (Winter)	Growing	Growing	Growing	Growing	Harvesting	Harvesting				Sowing	Sowing	Growing
Spring Wheat			Sowing	Sowing	Growing	Growing	Growing	Harvesting	Harvesting			
Rice					Sowing	Sowing	Growing	Growing	Growing	Harvesting	Harvesting	
Maize					Sowing	Growing	Growing	Harvesting				

Sowing
Growing
Harvesting

Following tables captures the total biomass potential in different months along the year.

Table 12: Total Surplus Biomass Potential of Afghanistan

Crop	Month of availability	Total available (000 Tons)
Winter Wheat	July	1,130
Spring Wheat	October	282
Total		**1,412**

The Total crop potential available for energy generation in Afghanistan is 1.4 million Tons

3.1.2.2 Bangladesh

Rice is the staple food of Bangladesh and is produced on ~75% of the cultivated area. There are three varieties of rice - Boro, Aus and Aman, grown all over the country, except in the hilly south-east region. Apart from rice, other cereals grown are wheat and maize, which make up 10% of the total food crops cultivated. Bangladesh is also the second largest producer of jute and sugarcane is an important cash crop that is cultivated in all parts of the country. For the purpose of this study, the crop residue from rice and wheat only have been considered for their abundant and concentrated availability, highest RPR and high heat contents. Furthermore, only the residue that is burnt in the farms- like straws and stalks have been considered for deriving the surplus residue potential.

Table 13: Crop Residue Potential in 2017-18 in Bangladesh

Crop	Annual Production (000 Tons)	Gross Residue generated (000 Tons)	Surplus Residue Potential (000 Tons)
Rice			
- Boro Rice	18,014	30,624	8,575
- Aus Rice	2,134	3,628	1,016
- Aman Rice	13,656	23,215	6,500
Wheat	4,337	7,807	1,717
Maize	3,026	6,960	1,740
Jute	8,247	16,494	1,649
Sugarcane	4,442	1,333	520
Potato	10,216	4,086	1,553
Others (Pulses, Oilseeds, Vegetables, fruits)	17,403	5,445	1,054
Total	**81,475**	**99,591**	**24,324**
Energy Production (rice and wheat straws only)	**38,141**	**57,212**	**15,629**

Source: Bangladesh Grain and Annual Feed Report, 2018

The gross residue generated from wheat and rice is 57.2 million Tons, of which 15.6 million Tons is the Surplus Potential derived from straws and stalks that can be used towards energy generation.

Zonal distribution of residue produced:

Rice is the dominant crop grown in Bangladesh and covers about 75% of the cropped area. The aman variety comprises of two types- transplanted aman, grown everywhere in Bangladesh and broadcast aman, grown in south and north-east divisions. Boro rice is grown in Sylhet division, while aus is a very scattered crop mostly cultivated in Khustia, Jessore, Comilla and Chittagong divisions. Wheat is cultivated as a winter crop in the drier Northern divisions. Jute is cultivated in the low-lying areas of Brahmaputra-Jamuna and Padma floodplains. Most of the sugarcane is cultivated in the Sylhet, Comilla, Chittagong and Dhaka divisions.

Figure 44: Zonal Distribution of Total Residue Produced in Bangladesh

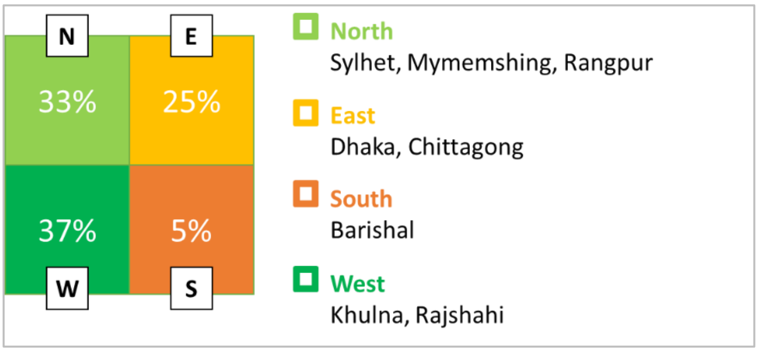


Table 14: Crop Harvesting Seasons in Bangladesh

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rice- Aman			Sowing	Sowing	Growing	Growing	Transplanting	Transplanting	Growing	Growing	Harvesting	Harvesting
Rice- Boro	Sowing	Growing	Growing	Harvesting	Harvesting	Harvesting						Sowing
Rice- Aus			Sowing	Sowing	Growing	Growing	Harvesting	Harvesting				
Wheat	Growing	Growing	Growing	Growing	Harvesting	Harvesting					Sowing	Sowing
Maize	Growing	Growing	Harvesting								Sowing	Sowing
Jute			Sowing	Sowing	Growing	Growing	Harvesting	Harvesting				
Sugarcane	Sowing	Sowing	Sowing	Growing	Growing	Growing	Growing	Growing	Growing	Growing	Harvesting	Harvesting

Sowing
Transplanting
Growing
Harvesting

Following tables captures the total biomass potential in different months along the year.

Table 15: Total Biomass Potential in Bangladesh

Crop	Month of availability	Total available (000 Tons)
Boro Rice	July	7,566
Aus Rice	September	896
Aman Rice	January	5,735
Wheat	July	1,431
Total		**15,629**

The Total crop potential available for energy generation in Bangladesh is 15.6 million Tons

3.1.2.3 Bhutan

The major cereal crops grown in Bhutan are maize and rice (94%) along with small quantities of wheat, barley, buckwheat, etc. Bhutan also cultivates large quantities of vegetables and fruits in rotation with rice in the wetland agricultural areas. The spices are cultivated at higher altitudes and as such are difficult to aggregate for residue. Rice and wheat are cultivated in the central region, while maize is cultivated in the eastern dzongkhags only. For the purpose of this study, the crop residue from only cereals has been considered for their quantity and concentrated availability, highest RPR and high heat contents. Furthermore, only the residue that is burnt in the farms- like straws and stalks have been considered for deriving the surplus residue potential.

Table 16: Crop Residue Potential in 2016-17 in Bhutan

Crop	Annual Production (000 Tons)	Gross Residue generated (000 Tons)	Surplus Residue Potential (000 Tons)
Rice	86	146	41
Maize	94	216	54
Wheat & other cereals	11	20	4
Oilseeds, Pulses, Spices	13	7	2
Vegetables & Fruits	182	36	4
Total	**386**	**426**	**105**
Energy Production (Cereal straws only)	**191**	**334**	**87**

Source: Bhutan RNR Statistics*, 2017*

The gross residue generated from cereal crops is 0.3 million Tons, of which 0.087 million Tons is the Surplus Potential derived from straws and stalks that can be used towards energy generation.

Zonal distribution of residue produced:

In Bhutan, rice is cultivated in the mid altitude regions with assured irrigation in Wangdue, Punakha, Trashigang and Mongar dzongkhags. Maize and other cereals are cultivated in the eastern dzongkhags.

Figure 45: Zonal Distribution of Total Residue Produced in Bhutan

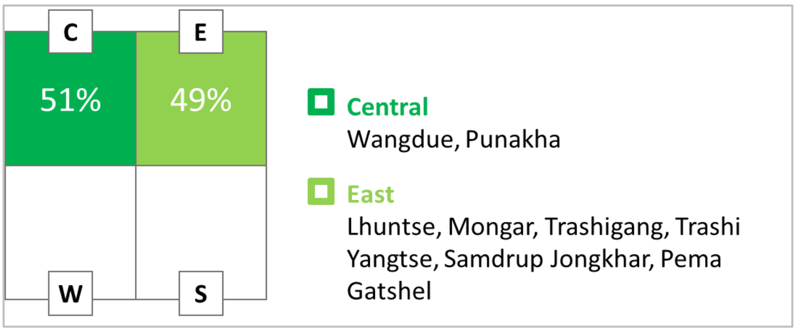


Table 17: Crop Harvesting Seasons in Bhutan

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rice		Sowing	Transplanting	Growing	Growing	Sowing	Transplanting	Growing	Growing	Harvesting	Harvesting	
Maize			Sowing	Sowing	Growing	Growing	Harvesting	Harvesting				
Wheat & other cereals	Growing	Growing	Growing	Harvesting	Harvesting						Sowing	Sowing

Sowing
Transplanting
Growing
Harvesting

Following tables captures the total biomass potential in different months along the year.

Table 18: Total Biomass Potential of Bhutan

Crop	Month of availability	Total available (000 Tons)
Rice	July and December	36
Maize	September	47
Wheat & other cereals	June	4
Total		**87**

The Total crop potential available for energy generation in Bhutan is 0.087 million Tons

Due to the mountainous terrain and distributed geographic cultivation of crops in the country the energy generation potential is calculated to be negligible. The energy generation potential from crop residue in Bhutan has been excluded from this study.

3.1.2.4 India

Rice is the predominant Kharif crop in India, while wheat is the Rabi crop, contributing to 40% and 35%, respectively, to the total food-grain production. Their production is largely concentrated in the Northern and Eastern states. India is also the second largest producer of sugarcane in the world and it contributes to ~45% of the total crop production in the country. Apart from food-grains, cotton is also produced in the Western and Southern states, while jute is grown largely in the Eastern States. Pulses and oilseeds are cultivated in the Western parts of the country and contribute to 20% of the total food production. The vast and uneven distribution of crops in the country makes it difficult to aggregate the crop residue in a timely and methodic manner. For the purpose of this study, we have considered zonal allocation of the crops based on their quantity harvested. Furthermore, only the residue that is most prone to burning in the fields- like straws and stalks of rice and wheat has been considered for deriving the surplus residue potential.

Table 19: Crop Residue Potential in 2017-18 in India

Crop	Annual Production (000 Tons)	Gross Residue generated (000 Tons)	Surplus Residue potential (000 Tons)
Rice	112,910	191,947	53,745
Wheat	99,700	179,460	39,481
Maize	26,000	59,800	14,950
Coarse cereals	46,990	84,582	18,608
Cotton	34,325	130,435	80,870
Jute & Mesta	10,500	21,000	2,100
Sugarcane	353,220	141,288	55,102
Pulses	25,230	50,460	19,175
Oilseeds	35,441	53,162	15,948
Total	**744,316**	**912,134**	**299,980**
Energy Production (rice and wheat straws only)	**212,610**	**318,915**	**80,323**

Source: Annual Report 2018, Department of Agriculture, Cooperation & Farmers Welfare

The burning of crop residue is largely followed for two crops in India - Rice and Wheat. Taking into consideration only the farm residues of these two crops, the gross residue potential is 319 million Tons, of which 80.3 million Tons is the Surplus Potential derived from straws and stalks that can be used towards energy generation.

Zonal distribution of residue produced:

In India, rice is majorly cultivated in Uttar Pradesh, Punjab, West Bengal and wheat is cultivated in Uttar Pradesh, Punjab, Haryana and Madhya Pradesh. Uttar Pradesh is also one of the highest producers of sugarcane followed by Maharashtra, Karnataka and Tamil Nadu. Cotton is mainly cultivated in Gujarat and Maharashtra, while Jute is concentrated in the eastern and north-eastern states of West Bengal, Bihar and Assam.

Figure 46: Zonal Distribution of Total Residue Produced in India

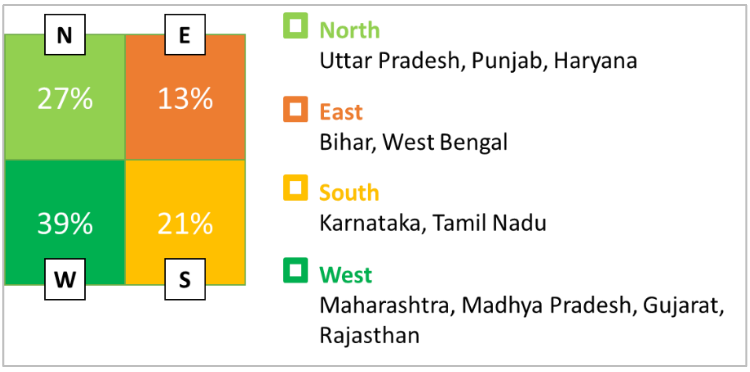


Table 20: Crop Harvesting Seasons in India

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rice						Sowing	Sowing	Growing	Growing	Growing	Harvesting	Harvesting
Wheat	Sowing	Growing	Growing	Harvesting	Harvesting							Sowing
Maize						Sowing	Sowing	Growing	Growing	Harvesting	Harvesting	
Cotton	Growing	Growing	Growing	Harvesting	Harvesting				Sowing	Sowing	Growing	Growing
Jute				Sowing	Sowing	Growing	Growing	Harvesting	Harvesting			
Sugarcane	Sowing	Sowing	Sowing	Growing	Growing	Growing	Growing	Growing	Growing	Growing	Growing	Harvesting

Sowing
Growing
Harvesting

Following tables captures the total biomass potential in different months along the year.

Table 21: Total Biomass Potential of India

Crop	Month of availability	Total available (000 Tons)
Rice	January	47,422
Wheat	June	32,901
Total		**80,323**

The Total crop potential available for energy generation from rice and wheat crops in India is 80.3 million Tons

3.1.2.5 Nepal

The agricultural crops grown in Nepal are divided into two broad categories - food crops and cash crops. The important food crops grown in Nepal are rice, maize, wheat, millets and other coarse cereals, of which rice contributes to more than 50% of the total production. Around 80% of rice is grown in the Terai regions, which receive ample rainfall and are conducive for rice cultivation. Potato is also grown in large numbers in the hilly regions and as such their cultivation is scattered. The cash crops-sugarcane, jute, tobacco, tea and spices are also cultivated in the Terai regions and are used for exports. The pulses and oilseeds are produced for domestic consumption and their residue aggregation is difficult, given the topography of Nepal.

For the purpose of this study, we have considered the residue generation from rice and wheat only, which are available in the Eastern and Central districts of Nepal, which allow for easy collection. Furthermore, only the residue that is most prone to burning in the fields- like straws and stalks of rice and wheat have been considered for deriving the surplus residue potential.

Table 22: Crop Residue Potential in 2017-18 in Nepal

Crop	Annual Production (000 Tons)	Gross Residue generated (000 Tons)	Surplus Residue potential (000 Tons)
Rice	5,482	9,319	2,609
Wheat	1,880	3,384	744
Maize	2,550	5,865	1,466
Coarse cereals	370	666	147
Sugarcane	3,500	1,400	546
Potato	2,806	1,122	427
Pulses	390	780	296
Oilseeds	220	330	99
Total	**17,198**	**22,867**	**6,335**
Energy Production (rice and wheat straws only)	**7,732**	**11,598**	**3,045**

Source: Nepal Statistical Yearbook

The gross residue generated from wheat and rice is 11.6 million Tons, of which 3 million Tons is the Surplus Potential derived from straws and stalks that can be used towards energy generation

Zonal distribution of residue produced:

Rice, wheat and maize are grown in the Terai and hilly regions of the country. They are mostly concentrated in the Eastern and Central regions of Dhanusha, Sarlahi, Jhapa and Morang.

Figure 47: Zonal Distribution of Total Residue Produced in Nepal

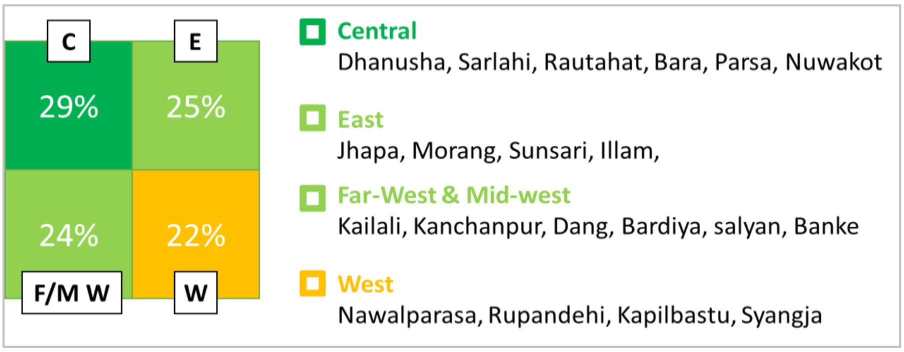


Table 23: Crop Harvesting Seasons in Nepal

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rice						Sowing	Sowing	Growing	Growing	Growing	Harvesting	Harvesting
Maize			Sowing	Sowing	Growing	Growing	Harvesting	Harvesting				
Wheat	Growing	Growing	Growing	Harvesting	Harvesting					Sowing	Sowing	Growing

Sowing
Growing
Harvesting

Following tables captures the total biomass potential in different months along the year.

Table 24: Total Biomass Potential of Nepal

Crop	Month of availability	Total available (000 Tons)
Rice	July and December	2,302
Wheat	June	743
Total		**3,045**

The Total crop potential available for energy generation in Nepal is 3 million Tons

3.1.2.6 Pakistan

The major crops cultivated in Pakistan are wheat, rice, maize, cotton and sugarcane. Wheat contributes to ~60% of the total cereal production and is grown in the eastern province of Punjab. Punjab is also the highest cultivator of sugarcane and cotton. Pakistan also produces oilseeds and pulses in high quantities; however, their residue is difficult to aggregate due to their vast spread across all the provinces and lower residue generation potentials. Most of the residue generated from pulses and oilseeds are utilized for cattle feed.

For the purpose of this study, the crop production and residue generation from only the rice and wheat have been considered for their reliability in cultivation, harvesting and high concentration in predetermined locations. Furthermore, only the residue that is most prone to burning in the fields- like straws and stalks of rice and wheat have been considered for deriving the surplus residue potential

Table 25: Crop Residue Potential in 2017-18 in Pakistan

Crop	Annual Production (000 Tons)	Gross Residue generated (000 Tons)	Surplus Residue potential (000 Tons)
Wheat	25,490	45,882	10,294
Rice	10,320	17,544	4,912
Maize	5,700	13,110	3,278
Coarse cereals	504	907	200
Cotton	1,935	7,353	4,559
Sugarcane	81,102	32,441	12,652
Pulses	125	250	95
Oilseeds	3,555	5,333	1,600
Total	**128,731**	**122,820**	**37,389**
Energy Production (rice and wheat straws only)	**36,314**	**54,471**	**12,912**

Source: Pakistan Economic Survey 2017-18

The burning of crop residue is largely followed for two crops in Pakistan - Rice and Wheat. Taking into consideration only the farm residues of these two crops, the gross residue potential is 54.4 million Tons, of which ~13 million Tons is the Surplus Potential derived from straws and stalks that can be used towards energy generation

Zonal distribution of residue produced:

In Pakistan, rice, wheat and cotton are cultivated in the irrigable lands in the eastern provinces of Punjab and Sindh. Sugarcane is cultivated to some extent in the Khyber Pakhtunkhwa along with Punjab and Sindh, while maize is concentrated in Sindh and Khyber Pakhtunkhwa provinces.

Figure 48: Zonal Distribution of Total Residue Produced in Pakistan

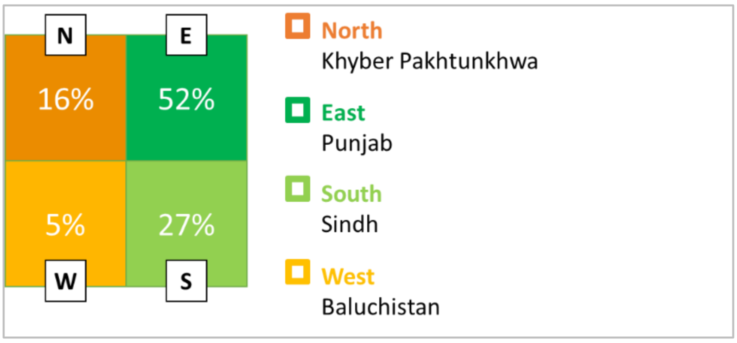


Table 26: Crop Harvesting Seasons in Pakistan

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wheat	Sowing	Growing	Growing	Harvesting	Harvesting							Sowing
Rice						Sowing	Sowing	Growing	Growing	Growing	Harvesting	Harvesting
Maize			Sowing	Sowing	Sowing	Growing	Growing	Harvesting	Harvesting			
Cotton	Growing	Growing	Growing	Harvesting	Harvesting				Sowing	Sowing	Growing	Growing
Sugarcane	Sowing	Sowing	Sowing	Growing	Growing	Growing	Growing	Growing	Growing	Growing	Harvesting	Harvesting

Sowing
Growing
Harvesting

Following tables captures the total biomass potential in different months along the year.

Table 27: Total Biomass Potential of Pakistan

Crop	Month of availability	Total available (000 Tons)
Wheat	June	8,578
Rice	January	4,334
Total		**12,912**

The Total crop potential available for energy generation in Pakistan is ~13 million Tons

3.1.2.7 Sri Lanka

The agricultural products in Sri Lanka are broadly divided in two categories: food crops (62%) and plantation crops (38%). Of the food crops, rice contributes the bulk of the products followed by maize, which are largely cultivated in the Eastern provinces of the country due to its humid climate and ample rainfall. Sri Lanka is also one of the top global producers of Manioc, a tuber, which is grown in large quantities all over the country. However, the crop does not produce enough residue and is used as cattle feed and manure purposes. The potential for energy generation from manioc is still in the research phase and is excluded from our study.

For the purpose of this study, the crop production and residue generation from only rice has been considered for their reliability in cultivation, harvesting and high concentration in predetermined locations. Furthermore, only the residue that is most prone to burning in the fields- like straws and stalks of rice and wheat have been considered for deriving the surplus residue potential

Table 28: Crop Residue Potential in 2016-17 in Sri Lanka

Crop	Annual Production (000 Tons)	Gross Residue generated (000 Tons)	Surplus Residue potential (000 Tons)
Rice	2,383	4,051	1,134
Maize	196	451	113
Manioc	306	122	47
Potatoes	73	29	11
Spices	58	12	1
Vegetables	237	47	5
Total	**3,253**	**4,713**	**1,311**
Energy Production (rice straw only)	**2,383**	**3,575**	**1,001**

Source: Economic and Social Statistics of Sri Lanka, 2018

The gross residue generated from rice is 3.5 million Tons, of which 1 million Tons is the Surplus Potential derived from straws and stalks that can be used towards energy generation.

Zonal distribution of residue produced:

Rice is the major crop of Sri Lanka and 50% of it is cultivated in the Eastern Province in the districts of Mahaweli, Ampara and Polonnaruwa, followed by Kurunegala, Gampaha and Kandy in the West. Maize is cultivated in the North in Anuradhapura, Ampara in the East and Monaragala in the South.

Figure 49: Zonal Distribution of Total Residue Produced in Sri Lanka

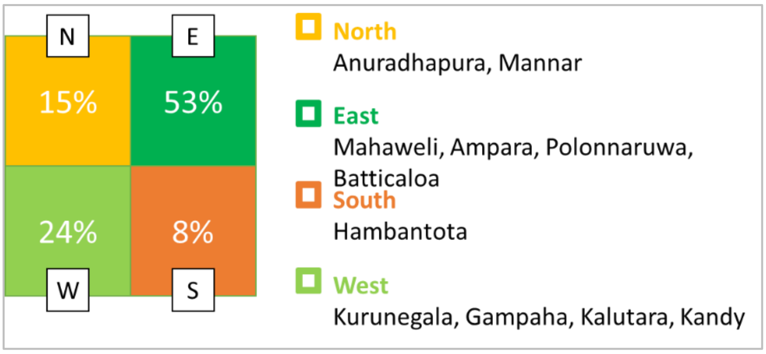


Table 29: Crop Harvesting Seasons in Sri Lanka

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rice (Maha)												
Maize												
Rice (Yala)												

Sowing
Growing
Harvesting

Following tables captures the total biomass potential in different months along the year.

Table 30: Total Crop Residue Potential of Sri Lanka

Crop	Month of availability	Total available (000 Tons)
Rice (Maha)	April	620
Rice (Yala)	October	381
Total		**1,001**

The Total crop potential available for energy generation in Sri Lanka is 1 million Tons

3.1.3 Summary - Crop Residue Potential of SAARC Member States

The following table provides the crop residue potential of all the SAARC Member States that can be used for energy generation through efficient harvesting, aggregation, collection, and setup of energy generation equipment for heat or power generation. The highest potential for energy generation can be realized in three Member States- India, Bangladesh, and Pakistan.

Table 31: Summary of Crop Residue Potential of SAARC Member States

Member State	Gross Residue Production (million Tons)	Surplus Residue Production (million Tons)
Afghanistan	6.4	1.4
Bangladesh	57.2	15.6
India	319	80.3
Nepal	11.6	3
Pakistan	54.4	13
Sri Lanka	3.5	1
Total	452	114

*Note: The above computations are based on information available for respective countries, as represented in Section 3.1.2. The energy generation potential for Bhutan and Maldives have been excluded from this **study due to their low crop residue production.***

3.1.4 Mechanization in Harvesting and Sowing Next Crop

Crop residue management has been an issue for the farmers, and with changing times it is necessary for them to adopt smart ways to dispose of the residue. Agricultural mechanization is an important input to agriculture for performing timely farm operations, reducing the cost of operation, and maximizing the utilization efficiency of costly inputs. Farmers have started applying new technologies that are environment friendly, thereby enabling them to produce crops more efficiently by using less power.

Due to heavy investments required for buying equipment, the farmers prefer to burn the crop residue. To disengage the farmers from this practice of burning the residue and encourage the usage of mechanized harvesting techniques, countries such as India, is providing subsidies in the range of 30-50% for different equipment. A list of key equipment processing crops in an efficient manner have been outlined below:

Figure 50: Mechanized Harvesting Machinery

01 – Rotavator

- Versatile machine that can be retro-fitted with a tractor, which is capable of turning soil in lesser time to prepare field for next sowing
- It is most effective in primary and secondary tillage of soil and land levelling without using extensive labour
- Price: USD 1,450- 3,000
- Rental: USD 10- 15 per hour

02 – Combine Harvester

- Versatile machine capable of combining three separate harvesting operations- reaping, threshing and winnowing in a single process
- The straw and other residue left behind is chopped up by the farmers and ploughed back into the field or used for animal bedding and feedstock
- Capable of harvesting variety of crops like wheat, barley, maize, oats, rye, soybeans
  - Price: USD 21,000- 30,000
  - Rental: USD 25-30 per hour

03 – Super SMS

- Retro- fitment that can be attached to the rear of a combine harvester
- Machine cuts the stubble into small pieces and spreads evenly in the field after which the farmers can sow wheat without setting the stubble on fire
- Price: USD 1,700- 2000
- Rental super SMS are not yet available and the government is putting thrust on retrofitting the existing Combine harvesters with them

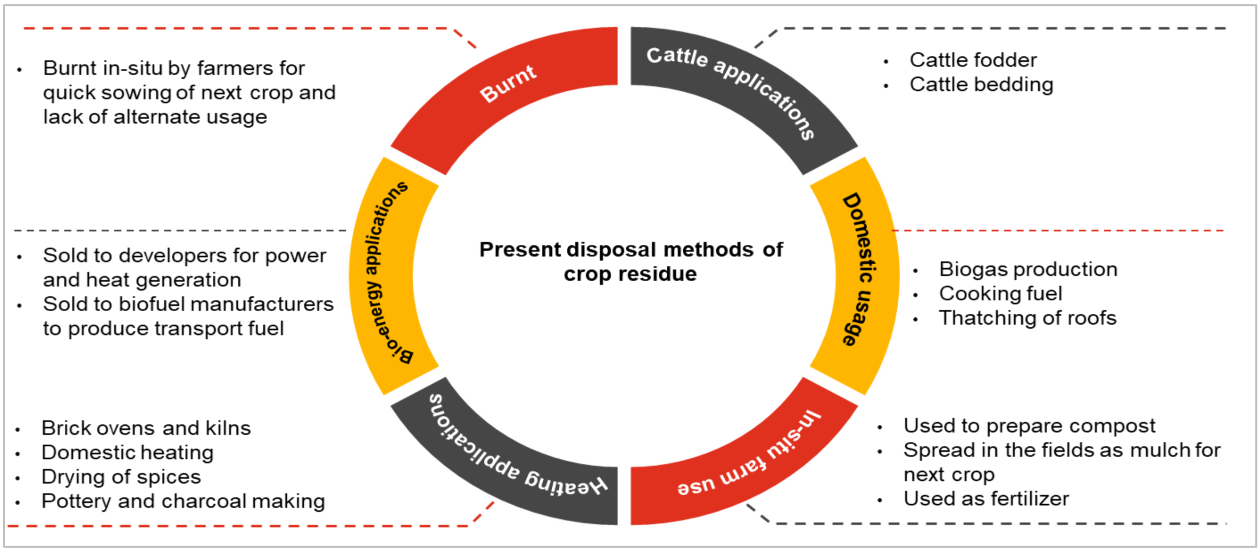
04 – Happy Seeder

- A tractor-mounted machine that cuts and lifts rice straw, sows wheat into the bare soil, and deposits the straw over the sown area as mulch
- Machine takes care of harvesting and sowing the next crop (wheat) in the same cycle without tilling the soil, thus making it most time and labour saving option
- Price: USD 2,500- 2,800

3.1.5 Current Disposal Methods Adopted

Farmers have been relying on various techniques for disposing off crop residue, which include using them as animal fodder, ploughing them back into the ground or burning them completely. Recently, newer methods of disposal are also being adopted for the utilization and disposal of these residues, like converting them into biofuels. However, this method is still in pilot stages of development and implementation. The most prevalent disposal technique is field burning of the residues. The common disposal methods of crop residue are shown below:

Figure 51: Prevalent Disposal Methods of Crop Residue

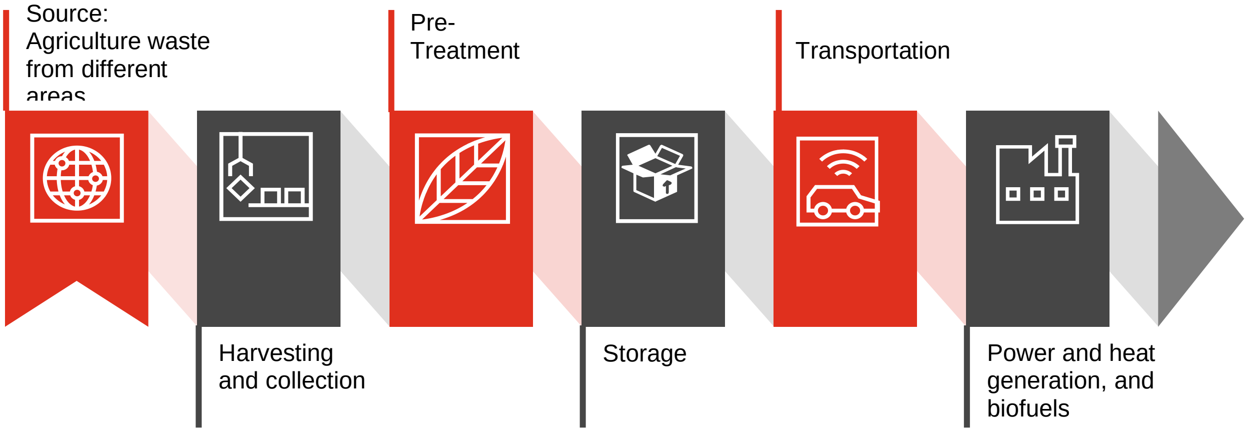


3.2 Supply Chain Mechanism

3.2.1 Overview of Supply Chain Mechanism in Member States

The supply chain of biomass is crucial to realize the full potential of bioenergy production. A biomass supply chain can include several stages with different agents such as farmers, aggregators, transporters, bio-refineries owners, end-user/client. The performance is highly dependent on the planning, bio-refineries owners, and operational activities. The efficient operation of all components of supply chain comprises of:

Figure 52: Supply Chain of Agricultural Waste



Harvesting and collection: The first step in biomass supply chain is harvesting and collection of feedstocks in an agriculture field. For agricultural biomass, harvesting is done by the farmers depending on the seasonal variation in crop season. Collection of residues is often done in easily accessible areas by the aggregators that are employed by the power plant developers at a village or regional level. However, the harvesting process must be done within a very limited timeframe and is greatly dependent on the crop that is to be sowed next and weather conditions.

The collection of crop residue from rural areas is the single largest bottleneck in the power generation supply chain. The issue is multi-faceted: a) farmers have a very small window for harvesting the crop and removing all the residue from the soil, b) farmers do not have money to employ skilled labor for removing the residue, c) farmers complain of very low compensation in return of their residue by project developers, d) delay in payments made by aggregators and e) lack of transportation means to reach the collection center, or in some cases the power plant facility.

In case of successful collection of residues from the farms, a common method of collecting is in the form of bales, where the straw left behind after the harvesting of grains is collected in rows and tied together to make bales. The size and shape of these bales is predetermined to suit the storage and transport required. However, if the moisture content of the biomass is high, it will require on-field drying before baling, which is again a time-consuming process.

Another less popular method and expensive to collect agricultural residue is by converting them to pellets or briquettes. These pellets/briquettes are easier to store and transport, especially over large distances and at lower costs. However, special machines and equipment are required for converting the residue in pellets/briquettes which are not affordable to farmers. Generally, this equipment for such conversion is provided by an aggregator of residue or power plant owner to reduce his transportation costs.

Pre-treatment: Once the biomass is harvested and collected, pre-treatment is done to ensure high quality of residue, which includes drying and/or densification to pellets, etc. Such processes ensure desired requirements of biomass including higher energy content and lower moisture content, which also facilitates ease of transportation and storage of the residue. Some residue can be directly combusted or gasified to generate heat or electricity, while others are pre-treated to facilitate the energy conversion process and increase the energy density as well as comply with potential specifications on volume, moisture content and standards.

Storage: In most cases, biomass must be stored between different stages of the supply chain for shorter or longer periods before being used for heat or power generation. The harvesting seasons for agricultural crops are often short and scattered across the year. To ensure a stable supply of biomass and always meet the demand, storage solutions are of great importance. The biomass stored at the collection terminals has the facility to keep the fuel and feedstock dry, protecting it from both rain and groundwater. The storage area is determined depending on the weather and type of biomass. It can be stored in a covered farm shed, silos for seeds and husks, or temperature-controlled collection terminals.

In most cases the residue is stored at various collection centers, which are closer to the farms and are only transported to the plant facility when its scheduled. The storage facility at the plant site generally has enough space to contain 7-15 days of residue for immediate utilization.

Transportation and handling: Biomass feedstock are mostly aggregated from large areas spanning hundreds of acres and villages, which are not always in close proximity to a power plant or upgrading facility. There are several steps in the supply chains, between which transportation is likely to be required, both of untreated feedstock and upgraded fuel. Any untreated biomass is difficult and bulky to transport adding to the cost of transportation.

There are many different options for transporting biomass and biofuel, and the most appropriate mode of transportation depends on the type, stage in the supply chain, distance of transportation as well as geographic and infrastructure conditions. Road transport is the most convenient solution since all farms can be reached in that way.

3.2.2 Storage Methods and Costs

Efficient storage for biomass is important to account for seasonality of production and ensure regular supply to the biomass utilization plant. The storage method type will depend on the properties of the residue, like type, weight, size, moisture content, and bulk density. The residue is pretreated and handled to reduce storage space and transportation cost. Most straw-based residues are compacted into large round bales. Husk-based residues are converted to pellets or briquettes and cobs are tied together and stored in bags.

This pretreatment of residue has certain advantages and disadvantages, like denser fuel pellets offer cost saving in transportation and storage, but the drawback is that the process results in feedstock loss. Similarly, corn cobs and stoves stored in bags require less storage space, but the inherent moisture content of the cobs decomposes the residue faster. The longer the biomass is stored, loss due to anaerobic biodegradation will increase.

Most plant developers establish regional processing centers to aggregate, process, store and transport the biomass when needed to realize significant cost reductions. This pretreated biomass can then be transported to the plant site for energy generation as and when required.

If the residue storage is done on the farmer's premises (like open field, trees, rooftop storage etc.) it can be assumed that the storage cost is negligible for the farmer.

In cases where the residue from a region are aggregated at a collection terminal for intermediary storage a warehouse/ facility will need to be taken on lease. Considering the seasonal variation of crops, the facility must be rented for the entire year. The rental of such a facility is paid by the power plant operator in most cases.

3.2.3 Transportation of Crop Residue and The Costs Associated

The transportation of residue from the farms to the collection terminals or power plant is the most important cost factor in the biomass supply chain. The transport cost is a function of type of residue, form of the residue- pellets, briquettes, bales, bundles or loose, type of transport means (vehicle) and distance to be travelled. Transportation can occur in different stages, depending on the business model of the operator, from farms to collection terminals and from there onwards to plant site. Transportation by tractor trailer and trucks is most common, while rail is used by some large-scale operators. The collection and transport of the residue is a time-consuming activity owing to the vast spread of fields, inaccessible areas, lack of transportation means and poor conditions of roads. Based on primary discussions with key stakeholders a transportation cost of USD 7-10/Tons is charged by farmers who supply their residue to the plant site

Drying and densification of the residue with equipment that can be located close to the villages can reduce this transportation cost significantly. Crop residue densification, such as palletization or briquetting, is suggested for efficient transportation of biomass over longer distances for their compact size and subsequent reduction of transportation costs.

Figure 53: Process of Pelletizing and Briquetting

Pelletization

- Process of molding or compressing a residues into the shape of a pellet.
  A broad range of various materials are pelletized includes wood pellets that are frequently used as fuel and pellets from crop residue for animal feed.

Briquette

- Briquette is a compressed block of combustible biomass material that can be used to fire in combusters for generating heat or energy. It is a process similar to that of making pellets, but on a larger scale. Moisture content of briquettes can be as low as 4%, which yields higher energy output and emissions when combusted

Advantages of briquetting to pelletizing

Investments costs: The cost is lesser for a briquetting plant, for press as well as for all other installations such as electrical installation, cooling, size of buildings, etc.

Operational costs: Power consumption is lesser, especially for the raw material does not need to be reduced to the same extend. The costs of spare parts are lower and operations are relatively simple

Simple technology: A press used for briquetting, can be handled by any skilled laborer and without much training.

Moisture content: A press can operate with a high range of moisture in crop residue, ranging between 6-18%.

Decentralized production: Briquettes can also be made on site, in the presence of raw material, thus saving considerably logistical costs

Logistical costs: Briquettes have a higher bulk density, but in contrast with pellets are better for shipping on a truck, as the density is adequate to reach the maximum capacity on a truckload.

Developing countries: Briquettes formed by a mechanical press can be created from various types of wastes, which includes agricultural wastes while replacing firewood and charcoal.

3.2.4 Study of Weather Effect on The Residue Before Sale/Utilization

As mentioned in the previous section, there is a time of only 2-3 weeks between the harvest and sowing of the next crop. The crop residue, if not burnt, is collected and stored in the form of bales till they are collected by the aggregators or by power plant owners. There is a delay of 1-2 months by the time this residue is transported to their end usage, during which time they may be affected by moisture if not stored properly in dry locations. An increase in the moisture content of the residue reduces the heat content of the fuel and does not ignite straightaway in the gasifiers. The wet residue also produces excessive smoke and ash when fired in the gasifier reactors, thus bringing down the efficiency of the process.

4 Energy Potential from Residue

The previous sections have established that ~450 million Tons of annual crop residue is available in the SAARC nations, of which ~114 million Tons of surplus residue can be used for energy generation purposes. The most popular and proven technologies have been explored in this section to determine the suitable technology for energy generation. The choice of technology is affected by many factors like type, quantity and quality of agriculture feedstock, desired energy form, economic viability, by-products produced and environmental standards. This section covers the different technologies used for biomass conversion to determine the most economically viable method to be implemented in the SAARC region.

4.1 Study of Different Technologies for Energy Generation Using Crop Residue

4.1.1 Combustion

Technology:

Combustion is the most common biomass conversion technology used at household as well as industrial levels over the past few decades. The technology is well suited for all types of biomass like municipal waste, agricultural waste, animal waste etc. with moisture content of up to 60% depending on the type of combustion system used. The chemical energy of the biomass is converted to heat energy through a series of chemical reactions when the biomass is burnt. This heat can be used directly for generating electricity or for heating purposes directly. Combustion is well suited for capacities beyond 5 MW. Combustion comprises over 85% of installed capacity for biomass-based power production in India (excluding biomass cogeneration)[3]. Over the last few decades, modern biomass combustion technologies have emerged like fully automated pellet boilers, co-firing, and efficient combined heat and power production for a large variety of biomass resources.

Cost: The equipment and engineering cost of the system lies between of USD 1,000,000 –1,070,000/ MW.

Tariff: USD 0.134 – 0.14/kWh

Pros and cons: The technology is well suited for capacities beyond 5 MW for realizing maximum efficiency. The process uses incineration of the waste which also results in large emissions of flue gases. Additional capex may have to be incurred for the treatment of these gases to meet the country’s emissions standards.

4.1.2 Gasification

Technology:

Biomass gasification is a thermo-chemical conversion of solid biomass into a combustible gas mixture, called as producer gas, through a partial combustion route with less Oxygen than needed for complete combustion. This producer gas is a mixture of combustible gases consisting of Carbon Monoxide, Hydrogen and Methane. The producer gas can be used for electrical power generation, either through dual-fuel ICE or through 100% gas-fired spark ignition engines. The producer gas can also be used for heating purpose to replace conventional forms of energy in many applications like small boilers, furnaces, hot air generators, dryers, etc.

Gasification method is suitable for a large range of biomass feedstock like crops, other plants, agricultural and forest waste, sawdust etc. Gasification systems are well-suited for small-scale applications with an

[3] *Source: Energy Alternatives India (EAI)*

operational range of as low as 20 kW that can be scaled up to 2 MW. Biomass gasifiers of the ranges 10-25 MW are also been implemented in developed countries. This versatility of gasification to operate with different feedstock and operation range make it suitable for implementation in different regions depending on the availability of biomass. Gasification based systems can be coupled with a gas turbine for heat recovery and a steam turbine (combined cycle), thus offering improved efficiency. The technology is in pilot implementation phase in various parts of the world.

Cost: The equipment and engineering cost of the system in the range of USD 630,000 – 850,000/ MW.

Tariff: USD 0.12 – 0.13/kWh

Pros and cons: The technology makes use of thermal decomposition of the waste to produce heat, fuel oil and gases, all of which can be used as end-products for economic value. The producer gas is cleaner than the flue gases resulting from other processes and can be used as fuel directly without any further treatment. The technology also can work on a wide range of waste types (mainly solid biomass like wood chips and pellets and agricultural residues)[4] and sizes, requiring less pre-treatment. Some governments also offer subsidies, grants and incentives for the use of biomass gasification plants, thereby reducing capital costs. The technology is widely used in the rural areas in smaller capacities to utilize agricultural wastes, however installations in larger operational ranges are few.

4.1.3 Pyrolysis

Technology:

Biomass pyrolysis is a thermal decomposition of biomass occurring at very high temperatures in the absence of Oxygen. The products of biomass pyrolysis include biochar, bio-oil and gases including Methane, Hydrogen, Carbon Monoxide, and Carbon Dioxide. Depending on the thermal environment and the final temperature, pyrolysis will yield mainly biochar at low temperatures, less than 450 °C, when the heating rate is quite slow, and mainly gases at high temperatures, greater than 800 °C, with rapid heating rates. At an intermediate temperature and under relatively high heating rates, the main product is bio-oil.

Pyrolysis processes can be categorized as slow or fast. Slow pyrolysis takes several hours to complete and results in biochar as the main product. On the other hand, fast pyrolysis yields 60% bio-oil 20% biochar and 20% syngas and takes seconds for complete pyrolysis. Fast pyrolysis is currently the most widely used pyrolysis system. In either case, the gas or oil can be used as a fuel for firing the boiler for steam production and subsequent power production. The bio-oil has about twice the energy density of wood pellets, which could make it particularly attractive for long distance transport. So far, however, the technology is in demonstration phase for this application. Challenging technical issues include the quality of the pyrolysis oil (such as relatively high Oxygen content) and its long-term stability, as well as the economics of its production and use. Pyrolysis oil could be used in heat and/or power generation units or upgraded to transport fuel. Research is underway to explore the possibility of mixing pyrolysis oil with conventional crude oil for use in oil refineries.

Pyrolysis is a low-cost technology as compared to combustion, capable of processing a wide variety of feedstock like agricultural waste, wood, municipal solid waste. Typically, pyrolysis plants work well beyond 2 MW scale; thus, it can be said that pyrolysis takes off where gasification ends. Pyrolysis method is not well established anywhere in the world and is still in the R&D phase.

Cost: The equipment and engineering cost of the system is the range of USD 850,000/MW- USD 1000,000/MW **Tariff**: 0.13 –0.14 USD/kWh

[4] *Source: Energy Alternatives India (EAI)*

Pros and cons: Like gasification, the technology makes use of thermo-chemical combustion to produce syngas, bio-oil and char, all of which have high economic value. The technology works on a wide range of wastes in higher capacities. However, the initial capex of the equipment is quite high and is still in the R&D stages of implementation.

4.1.4 Anaerobic Digestion

Technology:

Anaerobic digestion is the process of producing methane rich biogas in the absence of Oxygen using bacteria-induced fermentation of organic matter for use in cooking or heating applications. This process is best suited for wet biomass sources like manure, kitchen and animal waste, waste water, agricultural waste, municipal waste, etc. The biogas produced is a mixture of 40-75% Methane gas, Carbon Dioxide along with traces of Hydrogen Sulphide and Ammonia.

The process produces a sludge along with the biogas which is non-toxic and odorless in nature. The sludge is also very rich in nitrogen and can be used further as fertilizer in the fields. Thus, the use of biogas plants provides a triple-fold benefit in rural areas: 1) production of low-cost clean gas for cooking 2) sludge that can be used as fertilizer in fields and 3) Deterrence from burning conventional firewood for heating purposes leading to health benefits

Anaerobic digestion is a commercially proven technology and is widely used in India, Pakistan and Bangladesh for treating wet organic waste and waste water. The technology is commonly used in small size, rural and off-grid applications for cooking purposes. Small household biogas plants are simple, low-cost, easy to install and maintain systems that have been in use for decades and are a common sight in rural India.

Furthermore, the concept of turning waste to gas is also being used commercially for production of Bio-CNG in developed countries. The systems use agriculture waste, with some quantities of animal manure and waste from food-processing units for production of Bio-CNG which is then filed in pressurized cylinders and used in automobiles. Few international companies are setting up similar Bio-CNG plants in India that will operate on paddy straw and other farm wastes and produce CNG that is economically competitive to fossil-fuel based CNG for use in automobiles (details presented in Section 4.7)

Cost: 250 –300 USD/unit for single household units

Tariff: Not Applicable (in case of household biogas plants)

Pros and cons: Anaerobic digestion by way of using a biogas plant is being used in the SAARC countries for many decades at a household level. The technology is being commercially used in developed countries in large scales for production of biogas using different types of wastes. The governments of most countries provide grants and subsidies to individuals installing a biogas plant at home.

4.1.5 Co-firing

Technology:

Co-firing is a low-cost option for efficiently converting biomass to electricity by adding biomass as a partial fuel in high-efficiency coal fired boilers. Biomass can provide as much as 15% of the total fuel input with modifications to the feed intake system, storage system and burners. In return, the biomass combustion efficiency increases to ~35-37% when cofired with coal.

The economics of cofiring is largely dependent on the location and proximity, power plant type and availability of low-cost biomass fuels. Fuel supply is the most important cost factor when evaluating this technology for commercial operations. The cost of the biomass depends on many factors like availability, climate, closeness to collection centers, and presence of industries that can handle the chosen biomass.

Cofiring biomass with coal offers several health and environmental benefits, as the resulting emissions is low in Sulphur Dioxide as well as Carbon Dioxide. Additionally, if an agro-industrial or forestry processing plant wishes to make more efficient use of the residues generated by co-producing electricity but has a highly seasonal component to its operating schedule, co-firing with a fossil fuel may allow the economic generation of electricity all year round.

Cost: The equipment and retrofitting cost of the system is the range of 420,000 – 500,000 USD/MW

Tariff: 0.13 – 0.135 USD/kWh

Pros and cons: The technology can be directly applied to existing coal-fired power plants by making modifications to the feed intake system, resulting in lower installation costs. However, only 15-20% of the entire feedstock will be replaced by agricultural residue and will only marginally reduce the tariffs. This technology should only be used when a coal-fired plant is in close proximity to the fields to reduce transportation costs and ensure fuel availability.

4.2 Selection of Suitable Technology for Energy Generation in SAARC Member States

The selection of a suitable technology for energy conversion depends on the physical nature and chemical composition of the feedstock, the final energy output required (heat, power and fuel) and cost of the technology. The table below compares the commercial aspects of each technology covered in Section 4.1.

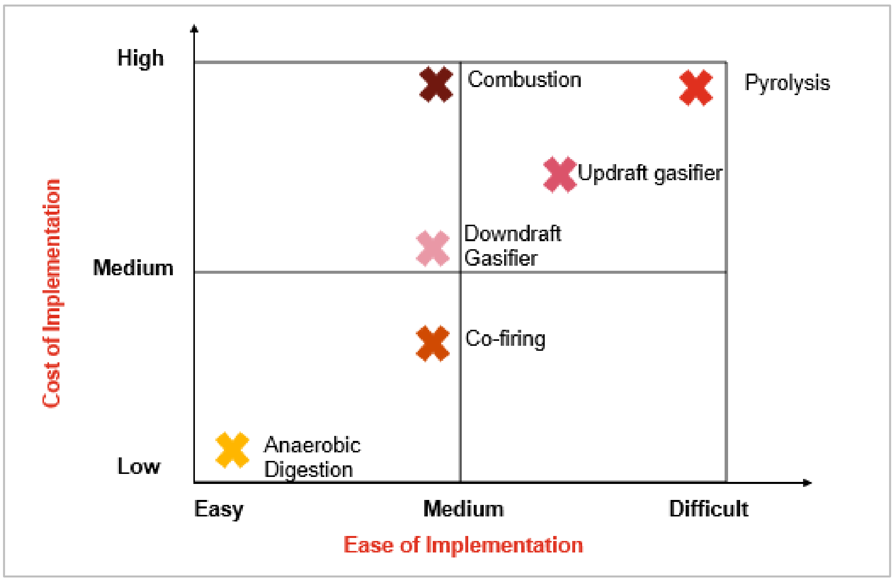
Table 32: Comparison of Commercial Aspects of Biomass Energy Conversion Technologies

Particular	Combustion	Gasification	Pyrolysis	Anaerobic Digestion	Co-firing
Installation Cost	1,000,000 – 1,070,000 USD / MW	630,000 – 850,000 USD/MW	850,000 – 1,000,000 USD /MW	250 –300 USD /unit	420,000 – 500,000 USD /MW
Tariff range	0.134 –0.14 USD /kWh	0.12 –0.13 USD /kWh	0.13 – 0.14 USD /kWh	Not Applicable	0.13 – 0.135 USD /kWh

The implementation costs will vary to some extent depending on the country, technological development, availability of government schemes and scale of installation. The tariff will also depend on the cost of the agricultural residue procured from the farmers.

The technologies can be compared on their cost and ease of implementation for selecting the most preferred option for each country as shown in Figure 54.

Figure 54: Potential Impact of Technology vis-à-vis Ease of Implementation



Anaerobic digestion is the most basic process for producing combustible gas and is used in small-scale, rural and off-grid applications at household levels. Biogas plants of higher capacities are being implemented in developed countries for commercial use, with some large-scale commercial plants operational in India. The process, however, works best with biomass or MSW with higher moisture content.

Combustion is the most common technique of producing heat and power from biomass, however they are typically installed in larger capacities of >5 MW. Cofiring of biomass in coal-based power plants is a more cost-effective method for power generation and requires only retrofitting costs.

Gasification is the most preferred biomass conversion process to directly produce syngas which can be used for heating or power applications. An updraft gasifier can be installed at higher capacities of 2 MW-20 MW but produce large amounts of chemicals and tar as a part of the syngas. A downdraft gasifier on the other hand is cheaper and produces lower tar content and is more suitable for use in internal combustion engines.

Pyrolysis technique produces char and bio-oil which can be used for further energy production. The bio-oil has potential as fuel but is contaminated with acids and must be treated before use, thus increasing the stages of the process. The technology is still in nascent stages of development and comes with a higher implementation cost.

In conclusion, biomass gasification technology best suits the need for energy generation owing to its ability to work with a large range of residue type and size and wide operational range that can be scaled up from smaller capacities at a village level installation to larger capacities at a regional or zonal level.

Table 33: Maturity Mapping of Biomass Energy Conversion Technologies

Member State	Anaerobic Digestion	Combustion	Co-firing	Gasification	Pyrolysis
Afghanistan	√	√	X	X	X
Bangladesh	√	√	X	√	X
Bhutan	√	√	X	X	X
India	√	√	√	√	√
Nepal	√	√	X	√	X
Pakistan	√	√	X	√	√
Sri Lanka	√	√	X	X	X

While technologies like anaerobic digestion and combustion of agricultural waste are well established across all the Member States, technologies like gasification is implemented only in larger Member States like India, Pakistan and Bangladesh. A mandate to co-fire biomass along with coal has been passed in India only, and suitable modifications to feedstock is under process. Pyrolysis on the other hand is in the nascent stages of development and has been installed on pilot basis on very small scale in India and Pakistan. It is recommended to install gasifiers in all the countries for its many advantages like proven and well-established technology, adaptability to a wide range of residues, low cost, easy implementation and scalability from few hundred kW to MW capacities[5].

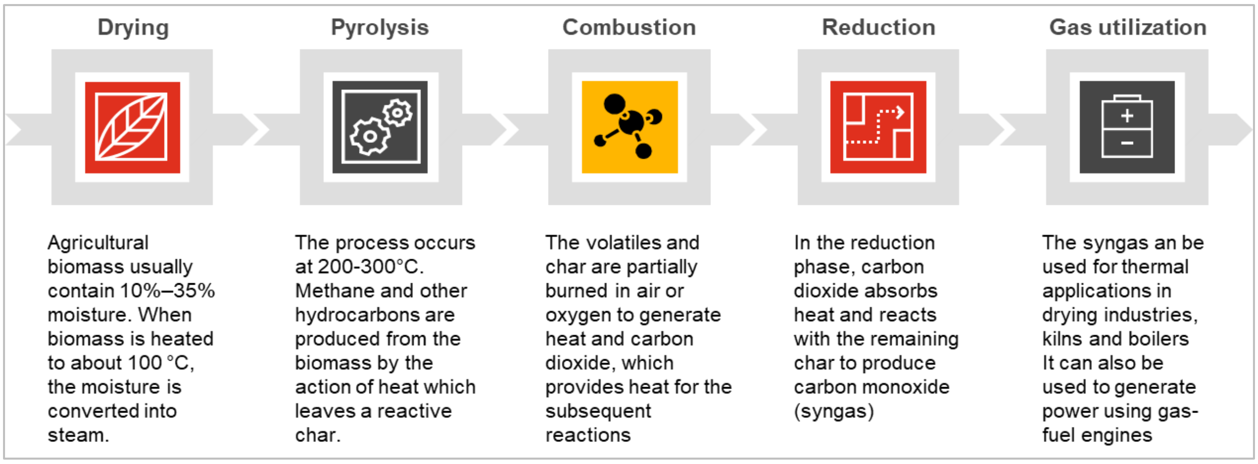
4.3 Study of Gasification Process and its Advanced Technologies

4.3.1 Gasification Process

Gasification is a partial oxidation process, in which a carbon source such as biomass is broken down into Carbon Monoxide (CO) and Hydrogen (H_2), plus Carbon Dioxide (CO_2) and hydrocarbon molecules such as Methane (CH_4). The end products of gasification are ash and slag, char, bio-oil and producer gas, or syngas. The syngas has a potential heat content (calorific value) equivalent to 25% that of natural gas if ambient air is used or 40% if Oxygen-enriched air is used. The syngas can be used as a fuel in place of diesel in IC engines or a 100% gas-fired spark ignition engine coupled with generator to produce electricity. The syngas can also be used for heating purposes in many applications like small boilers, dryers, furnaces etc.

The complete gasification system consists of a gasification unit called gasifier, purification unit and energy converter, burners or internal combustion engine. In the downdraft type of gasifier, the fuel is loaded into the reactor from the top. As the fuel moves down, it is subjected to drying and pyrolysis. Air is injected into the reactor in the oxidation zone, and through the partial combustion of pyrolysis products and solid biomass, the temperature rises to 1100°C. This helps in breaking down heavier hydrocarbons and tars. As these products move downwards, they enter the reduction zone where producer/syngas gas is formed by the action of Carbon Dioxide and water vapor on red-hot charcoal. The hot and dirty syngas is passed through a system of coolers, cleaners, and filters before it is sent to engines for generation of electricity. The syngas production process using a downdraft gasifier is depicted below.

Figure 55: Gasification Process



4.3.2 Preconditions for Biomass for Implementation

Biomass gasifiers need dry and uniform-sized fuel for smooth operations and higher efficiency. Most gasifiers operate on woody biomass like pellets and briquettes or loose pulverized biomass.

5 *Source: Energy Alternatives India (EAI)*

Figure 56: Types of Gasifier Biomass

Woody biomass	Loose biomass
• Pieces smaller than 5-10 cm in any dimension depending on the gasifier design • Bulk density of pellets/ briquettes: less than 250-300 kg/m^3	• Biomass to be pulverized before feed • Moisture content: upto 15-20% • Ash content: below 5% • Bulk density of loose biomass: less than 150 kg/m^3

4.3.3 Types of Biomass Gasifiers

Gasifiers are classified based on their density factor, which is the ratio of the solid matter a gasifier can burn to the total volume available. The gasifiers can thus be classified into dense phase gasifiers and lean phase gasifiers. In dense phase reactors, the feedstock fills up most of the space in the reactor and have a typical density factor of 0.08 – 0.3, while lean phase reactors have a typical density factor of 0.05 – 0.2.

The types of dense phase gasifiers used commercially are: Updraft, Downdraft and Crossdraft.

1

- In an **updraft gasifier,** biomass is loaded at the top of the gasifier and air is blown in at the bottom; thus, the flow of elements is counter-current, wherein the fuel flows downwards and the air flows upwards.
- It has properly defined zones for drying, partial combustion, pyrolysis and reduction. The gas formed in the reduction zone leaves the gasifier reactor along with the products of pyrolysis from the pyrolysis zone and steam from the drying zone.
- This type of gasifier produces gas that is contaminated by tar and is therefore too dirty to be used in an internal combustion engine. However, the syngas is rich in hydrocarbons and has a higher calorific value making it more suitable for heating applications, like furnaces.
- If the syngas is to be used for generating electricity it needs to be cleaned thoroughly using complicated and advanced technologies, thus increasing the capital cost

2

- In a **downdraft gasifier**, air is drawn downwards through the biomass. Thus, the flow of elements is co-current, wherein the fuel and air both flows downwards.
- In downdraft gasifiers, the pyrolysis zone is over the combustion zone and the reduction zone is under the combustion zone.
- The gasifier is so designed that the tar produced in the pyrolysis zone travels through the combustion zone where it is broken down and burnt. As a result, the mixture of gases exiting the gasifier are relatively cleaner.
- The strategic location of the combustion zone acts as a critical element for producing syngas with low tar content and can be used directly in gas engines for producing electricity

3

- The **crossdraft gasifier** is similar to that of the updraft one, except that the air enters from the side of the reactor, instead of the top.
- and the thermochemical reaction will occur progressively as the fuel descends down the reactor.
- The startup time for this gasifier is relatively shorter and very high temperature can be attained using this type of gasifier.

- The crossdraft gasifier is not used commercially as the other gasifiers provide more flexibility in type of fuel, size of fuel and ash content of the fuel

In lean phase gasifiers there is no distinction between the reaction zones and all the reactions- drying, combustion, pyrolysis and reduction- take place in a single large reactor chamber. The types of lean phase gasifiers are: Fluidized bed and Entrained flow.

1

- In **fluidized bed gasifiers**, the biomass is brought into an inert bed of fluidized material (e.g. sand, char, etc.). The fuel is fed into the fluidized system either above-bed or directly into the bed, depending upon the size and density of the fuel and how it is affected by the bed velocities.
- The fuel particles mix quickly with the bed material, resulting in rapid pyrolysis and release of large number of gases. Further gasification and tar conversion reactions occur in the gas phase.
- The reactors are equipped with internal cyclone to minimize char blowout and the ash particles are carried to the top of the reactor and must be removed if the gas is to be used in IC engines
- The major advantage of these reactors is their ability to control temperatures and ability to work with fluffy and fine-grained feedstock
- The major disadvantage of these reactors is their high tar content in the gas, incomplete carbon burnout and poor response to load changes

2

- In **entrained-flow gasifiers**, fuel and air are introduced from the top of the reactor, and fuel is carried by the air in the reactor. The operating temperatures are very high in the range of 1200–1600 °C, due to the short residence time of feedstock (0.5-4 seconds)
- Entrained-flow gasifiers can be used for any type of fuel so long as it has low moisture and ash content and is finely reduced.
- The advantage of entrained-flow gasifiers is that the gas contains very little tar.
- The disadvantage of this reactor is its very high temperatures which causes material handling and ash melting issues.

The key to a successful design of gasifier is to understand the properties, calorific content and thermal behavior of the fuel fed to the gasifier. The biomass gasification technology is an attractive option for rural development due to the proximity of agricultural biomass to these areas. Although the technology is expensive, gasification of agricultural residue to produce clean syngas has the highest energy conversion efficiency between 28%- 36%. Community participation, government subsidies and grants can be used to reduce the expensive installation and building cost. The commonly used reactors for energy generation are the updraft and downdraft gasifiers, with the former tolerant to large fuel sizes and wide variety of biomass residue, but the latter producing cleaner syngas that be used for direct electricity generation.

4.3.4 Selection of Gasifier Technology

Table 34: Types of Gasifiers

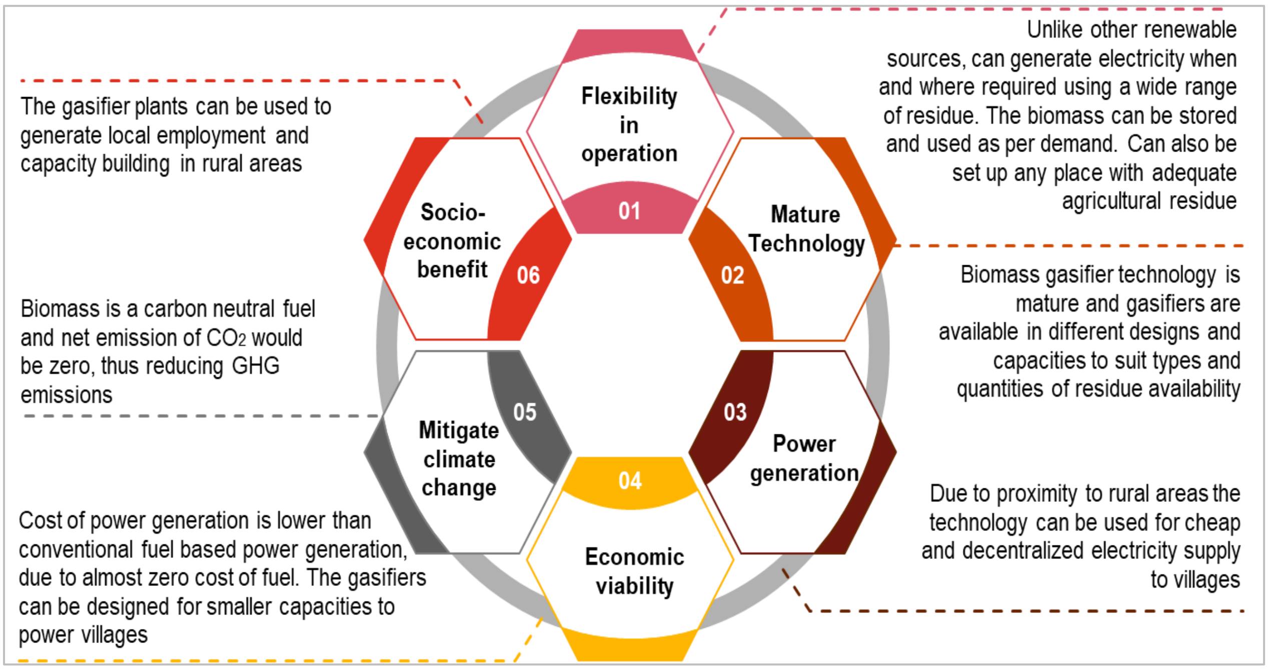
Gasifier type	Advantages	Disadvantages
Updraft	Simple design	High amount of tar produced
	High fuel to gas conversion efficiency	
	Accepts fuels with higher moisture content	

Gasifier type	Advantages	Disadvantages
	Accepts fuels of different and non-uniform sizes	Extensive and expensive gas cleaning techniques required if used for power application
Downdraft	Low tar content	Limited scale-up
	Cleaner gas produced	Strict fuel requirements- size, type and uniformity
	Gas can be used directly for power generation	High amount of ash and dust produced
	At lower loads, fewer particles are produced in the gas	At lower temperatures, more tar is produced
Cross draft	Applicable for small scale applications	High amount of tar produced
	Due to high temperatures, gas cleaning requirements are low	Strict fuel requirements- size, type and uniformity
		High amount of ash and dust produced
Fluidized bed	Single reactor and compact construction	Gas stream contaminated with fine dust particles
	Works with different feed stock sizes	Low biomass holds up in the fuel bed
	No clinker formation	Fuel flexibility between 0.1-1 cm size biomass only
Entrained-flow	Applicable for large systems	Very high temperature causes material handling and ash melting issues
	Short residence time of biomass	Very high capital cost
		Strict fuel requirements

The downdraft type gasifier is the preferred by developers as it produces cleaner gas and lower tar, thus reducing O&M costs for regular cleaning of filters.

4.3.5 Advantages of Biomass Gasification Technology

Figure 57: Advantages of Biomass Gasification



4.3.6 Factors Influencing Gasification

Table 35: Factors Influencing the Efficiency of Gasifiers

Energy content of fuel
Fuel with higher energy content provide better combustion and produce higher heating values. The energy content of selected biomass is higher when it is freshly obtained as compared to ones stored for weeks or months. The crops with highest heating values (MJ/kg) are sugarcane bagasse, cotton and jute and cereals. Sugarcane bagasse: 20 MJ/kg Jute: 19.7 MJ/kg Barley: 18.1 MJ/kg Maize cobs: 17.4 MJ/kg Cotton: 17.4 MJ/kg Wheat: 17.1 MJ/kg Rice: 15.5 MJ/kg
Fuel Moisture Content
Moisture content of the fuel is its inherent moisture plus surface moisture. A moisture content in the range of 10-15% by weight is desirable for self-sustaining combustion process. Igniting a fuel with higher moisture content is difficult and produces low quality gas and high ash. If a fuel with higher moisture content is used, a supplemental fuel must be added for successful combustion, which would defeat the objective of producing energy by biomass combustion.
Particle size and distribution
The particle size of the fuel affects the pressure drop across the reactor and the power that must be supplied to draw the air and gas through the gasifier. Irregular sized particles lead to large pressure drops in the gasifier, resulting in low temperature and high tar production. Gasifiers work best with uniform sized small particles/ pellets in the range of 8x4x4 cm to 10x5x5 cm.
Volatile matter content of fuel
The reaction in the pyrolysis zone give up volatile matter forming a vapor consisting of water, tar, oils and gases. Fuel with high volatile matter content produce more tar, causing problems to the IC engine. Crop residue generally have a volatile matter content of 63-80%, as compared to wood: 72-78%, coal: 40%
Ash content of fuel
Some amount of ash is left behind after the combustion stage, which also contain some unburnt fuel. Ash content and composition have an impact on the smooth running of a gasifier. Melting and agglomeration of ashes causes slagging or clinker formation. This slagging results in excessive tar formation and/or complete blocking of the reactor. Slagging does not occur with fuel having ash content below 5%. While woods chips have the lowest ash content of 0.1%, rice husks contain ~16-23%. Ash contents of some other crop residues is shown below: Cotton: 17.2% Barley straw: 10.3% Wheat stalks: 7.4% Peanut husks: 0.9%asd

4.3.7 By-Products of Gasification

The gasification of biomass is a thermal treatment, which results in a high proportion of gaseous products and small quantities of bio-char (solid product) and ash, along with bio-oil.

Ash is the inorganic, non-combustible components that are left after complete combustion has taken place. Ash is not always waste; it can be used for different purposes like, soil conditioner, fertilizer or as input in concrete industry. Biomass ash compared to coal ash contains more environmentally friendly materials. Ash is an intrinsic property of the fuel, which is governed by the percentages of chlorine potassium, nitrogen and Sulphur compounds of the biomass.

Bio-oil is the liquid produced from the condensation of vapor of a pyrolysis reaction. It is a liquid emulsion of oxygenated organic compounds, polymers, and water. It has potential to be used as a fuel oil substitute. The bio-oils have heating values of 40%–50% of that of hydrocarbon fuels. Liquefied biomass can be easily pumped, stored, fed to useful processes, and more compatible to chemical modification, processing, or extraction.

Bio char is a fine-grained, carbon-rich, porous product remaining, after plant biomass has been subjected to thermo-chemical conversion process (pyrolysis) at low temperature (350–600°C), in an environment with little or no oxygen. Bio char is not a pure carbon, but rather mix of Carbon (C), Hydrogen (H), Oxygen (O), Nitrogen (N), Sulphur (S) and ash in different proportions. The crucial quality of bio char that makes it attractive as a soil amendment is its highly porous structure, potentially responsible for improved water retention and increased soil surface area.

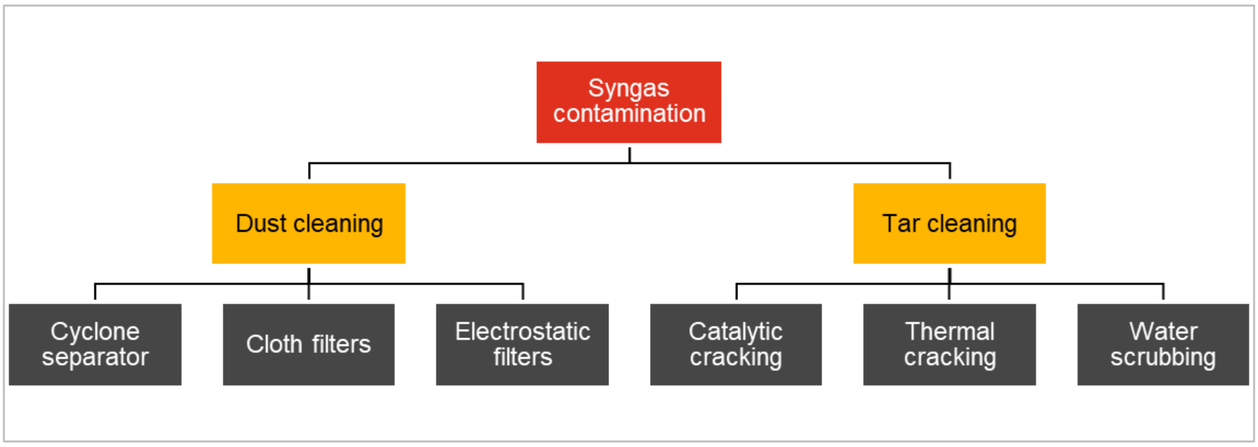
Table 36: Uses, Advantages and Disadvantages of By-Products

By-products	Uses	Advantages	Disadvantages
Ash	Raw material for fertilizer	It is highly economical.	Air pollution
	Component in the manufacture of building material	Environment friendly	Presence of heavy metals in ash hampers pH value of soil
Bio-oil	Fuel oil substitute	Utilization in small-scale power generation systems as well as use in large power stations	Poor volatility
	Agri-chemicals	High-energy density	High viscosity
	Source of organic compounds	Ease of storage and transport of bio-oil	Corrosiveness
Bio char	Fuel for cooking and heating	It balances acidic soil towards a neutral pH	Soil loss by erosion can be an issue when top dressing bio char to soils
	Additive for soil amendment	Moisture and nutrient retention improvements	High rates of bio char can be harmful to earthworms
	Composting agent	It has the affinity for absorbing contaminants in the soil	Some bio chars can act as contaminants of soil

4.3.8 Cleaning Process

The gases formed during gasification of biomass are contaminated by tar and dust. The degree of contamination will depend on the type of residue used, size of feedstock, and gasification process employed. The gas must be cleaned for further use in heat or energy applications, while the tar should be removed to prevent erosion, corrosion of the reactor and to minimize environmental hazards. The common methods employed for cleaning of gas and tar are depicted below:

Figure 58: Syngas Cleaning Methods



4.3.8.1 Dust Cleaning

1. **Cyclone Separator**: These separation devices use the principle of inertia to remove particulate matter from the syngas. Cyclone separators, or cyclones, are pre-cleaners and are used to remove larger pieces of particulate matter. They are not proven efficient in removing smaller particulate matters and only 60-70% of dust can be cleaned from the gas stream using a cyclone.

Smaller feedstock particles generally cause high dust concentration in the syngas as compared to larger fuel blocks. The type of fuel also influences the dust contamination, where hardwoods fuel produces less dust than softwoods, like maize cobs.

2. **Cloth filters**: Cloth filters have proven to be an effective equipment for gas cleaning. However, they are sensitive to gas temperature and do not work well under 70°C, where the water in the gas condenses on the filters and obstructs the gas flow causing a pressure drop in the reactor. Cloth filters work well at high temperatures, but are subject to rapid build-up of dust, thus requiring frequent cleaning. These filers work best if they are used in conjunction with a pre-filtering step, like a woven glass-wool filter bag.

3. **Electrostatic filters**: These filters work on the principle of magnetically charging dust particles and separating them from the gas. It is the most efficient method of cleaning gas and meeting environmental compliance norms in many countries. The only barrier in their implementation is the high installation cost, making them economically viable in high-capacity power plants only.

4.3.8.2 Tar Cleaning

1. **Catalytic cracking**: Catalysts like dolomite are used for tar conversion at higher temperatures typically 800-900°C. The catalyst breaks down the tar deposition and prevent them from condensing on the reactor surface. The implementation of catalytic cracking is still in the pilot stage with limited success stories.

2. **Thermal cracking**: Thermal cracking of the tar is achieved at high temperatures at 800-1000°C. However, biomass derived tar is more refractory in nature and are harder to crack using thermal cracking alone. The surface of the reactor must be heated to a very high temperature and requires a significant energy supply, thus reducing the overall efficiency of the reactor. Thermal cracking is more effective when the fuel residence time inside the reactor is increased, while simultaneously reducing the contact surface area.

3. **Water scrubbing**: Water can cool and clean the contaminated syngas in a single operation and are available in two types: the scrubber and the heat exchanger. Water scrubbing is a widely used and more successful technique for physical removal of tar, but also results in loss of sensible heat and reduces efficiency of the reactor. The advantage of the water scrubber over other techniques is its small size. But it also has a few disadvantages like: increased power consumption in using a water pump, regular replacement of clean water and waste water disposal of the contaminated water.

4.4 Energy Generation Potential in SAARC Member States

The energy potential of each Member State is estimated based on their Gross crop residue potential and the subsequent Surplus crop residue potential, which is the residue left after any competing use (such as cattle fee, animal bedding, compost, heating and cooking fuel etc.). As the issue of crop residue burning is primarily focused around field-based residues like straws, stalks and leaves, only these have been considered to derive the Gross and Surplus residue potentials for rice and wheat. This surplus potential can be used for bioenergy generation using biomass gasification technology as discussed in the previous section. Based on this annual surplus residue potential, the annual power generation potential for different crops has been calculated as below:

Annual power generation potential = (Total Surplus crop residue) x (Collection Efficiency)/ (365 x 24 x P)

Where P= Tons of biomass required to produce 1 MW of electricity

The fuel consumption of different crops to produce power have been illustrated in Annexure 10.2.

The collection efficiency is the major factor affecting the power production potential for each Member State. In countries like India, Pakistan and Bangladesh the collection efficiency is considered at 75% of total surplus on a conservative scale. The collection efficiency in Sri Lanka has also been considered at 75% of total surplus because the rice production is adequate, assured and available in easily accessible areas. However, in smaller countries with difficult geographic terrain and uncertainties in production the barriers in collection of this residue increases. Hence, the collection efficiency in Afghanistan and Nepal is considered at 50% of total surplus. The region-wise power generation potential of each Member State has been illustrated below. The Crop production, gross residue production and surplus residue production of the respective country has been taken from Section 3.1.2.

4.4.1 Afghanistan

The annual production of wheat, the gross farm-residue and the surplus farm-residue is illustrated below.

Table 37: Crop Production and Surplus Residue Production of Identified Crops in Afghanistan

Crop	Total Crop Production (000 Tons)	Residue type	RPR	Gross Residue Generation (000 Tons)	Surplus Residue Generation (000 Tons)	Biomass Consumption Ratio (P)	Power Generation Potential (MW)
Wheat	4,280	Straw	1.5	6,420	1,412	1.4	58
Total	***4,280***			***6,420***	***1,412***		***58***

Assumptions for calculation of power generation potential:

Collection efficiency (C) = 50%

Biomass consumption (P) = As detailed for different crops in Annexure 10.2

Power generation capacity (MW) = (Surplus residue generation in Tons x C) / (24 x 365 x P)

Table 38: Summary of Power Generation Potential in Afghanistan

Total wheat production	4.2 million Tons
Gross residue generation from straws and stalks	6.4 million Tons
Surplus residue generation from straws and stalks	1.4 million Tons
Power generation potential using only field-based residue	58 MW

4.4.2 Bangladesh

The annual production of wheat and rice, their gross farm-residue and surplus farm-residue is illustrated below.

Table 39: Crop Production and Surplus Residue Production of Identified Crops in Bangladesh

Crop	Total Crop Production (000 Tons)	Residue type	RPR	Gross Residue Generation (000 Tons)	Surplus Residue Generation (000 Tons)	Biomass Consumption Ratio (P)	Power Generation Potential (MW)
Wheat	4,337	Straw	1.5	6,506	1,431	1.4	88
Rice	33,804	Straw	1.5	50,706	14,198	1.2	1,013
Total	***38,141***			***57,212***	***15,629***		***1,100***

Assumptions for calculation of power generation potential:

Collection efficiency (C) = 75%

Biomass consumption (P) = As detailed for different crops in Annexure 10.2

Power generation capacity (MW) = (Surplus residue generation in Tons x C) / (24 x 365 x P)

Table 40: Summary of Power Generation Potential in Bangladesh

Total wheat and rice production	38.1 million Tons
Gross residue generation from rice and wheat straws and stalks	57.2 million Tons
Surplus residue generation from rice and wheat straws and stalks	15.6 million Tons
Power generation potential using only these field-based residue	1,100 MW

4.4.3 India

The annual production of wheat and rice, their gross farm-residue and surplus farm-residue is illustrated below

Table 41: Crop Production and Surplus Residue Production of Identified Crops in India

Crop	Total Crop Production (000 Tons)	Residue type	RPR	Gross Residue Generation (000 Tons)	Surplus Residue Generation (000 Tons)	Biomass Consumption Ratio (P)	Power Generation Potential (MW)
Wheat	99,700	Straw	1.5	149,550	32,901	1.4	2,012
Rice	112,910	Straw	1.5	169,365	47,422	1.2	3,383
Total	***212,610***			***318,915***	***80,323***		***5,395***

Assumptions for calculation of power generation potential:

Collection efficiency (C) = 75%

Biomass consumption (P) = As detailed for different crops in Annexure 10.2

Power generation capacity (MW) = (Surplus residue generation in Tons x C) / (24 x 365 x P)

Table 42: Summary of Power Generation Potential in India

Total wheat and rice production	212.6 million Tons
Gross residue generation from rice and wheat straws and stalks	319 million Tons
Surplus residue generation from rice and wheat straws and stalks	80.3 million Tons
Power generation potential using only these field-based residue	5395 MW

4.4.4 Nepal

The annual production of wheat and rice, their gross farm-residue and surplus farm-residue is illustrated below.

Table 43: Crop Production and Surplus Residue Production of Identified Crops in Nepal

Crop	Total Crop Production (000 Tons)	Residue type	RPR	Gross Residue Generation (000 Tons)	Surplus Residue Generation (000 Tons)	Biomass Consumption Ratio (P)	Power Generation Potential (MW)
Wheat	2,250	Straw	1.5	3,375	743	1.4	30
Rice	5,482	Straw	1.5	8,223	2,302	1.2	110
Total	***7,732***			***11,598***	***3,045***		***140***

Assumptions for calculation of power generation potential:

Collection efficiency (C) = 50%

Biomass consumption (P) = As detailed for different crops in Annexure 10.2

Power generation capacity (MW) = (Surplus residue generation in Tons x C) / (24 x 365 x P)

Table 44: Summary of Power Generation Potential in Nepal

Total wheat and rice production	7.7 million Tons
Gross residue generation from rice and wheat straws and stalks	11.6 million Tons
Surplus residue generation from rice and wheat straws and stalks	3 million Tons
Power generation potential using only these field-based residue	140 MW

4.4.5 Pakistan

The annual production of wheat and rice, their gross farm-residue and surplus farm-residue is illustrated below.

Table 45: Crop Production and Surplus Residue Production of Identified Crops in Pakistan

Crop	Total Crop Production (000 Tons)	Residue type	RPR	Gross Residue Generation (000 Tons)	Surplus Residue Generation (000 Tons)	Biomass Consumption ratio (P)	Power Generation Potential (MW)
Wheat	25,994	Straw	1.5	38,991	8,578	1.4	525
Rice	10,320	Straw	1.5	15,480	4,334	1.2	309
Total	***36,314***			***54,471***	***12,912***		***834***

Assumptions for calculation of power generation potential:

Collection efficiency (C) = 75%

Biomass consumption (P) = As detailed for different crops in Annexure 10.2

Power generation capacity (MW) = (Surplus residue generation in Tons x C) / (24 x 365 x P)

Table 46: Summary of Power Generation Potential in Pakistan

Total wheat and rice production	36.3 million Tons
Gross residue generation from rice and wheat straws and stalks	54.4 million Tons
Surplus residue generation from rice and wheat straws and stalks	13 million Tons
Power generation potential using only these field-based residue	834 MW

4.4.6 Sri Lanka

The annual production of rice, the gross farm-residue and the surplus farm-residue is illustrated below.

Table 47: Crop Production and Surplus Residue Production of Identified Crops in Sri Lanka

Crop	Total Crop Production (000 Tons)	Residue type	RPR	Gross Residue Generation (000 Tons)	Surplus Residue Generation (000 Tons)	Biomass Consumption Ratio (P)	Power Generation Potential (MW)
Rice	2,383	Straw	1.5	3,575	1,001	1.2	71
Total	***2,383***			***3,575***	***1,001***		***71***

Assumptions for calculation of power generation potential:

Collection efficiency (C) = 75%

Biomass consumption (P) = As detailed for different crops in Annexure 10.2

Power generation capacity (MW) = (Surplus residue generation in Tons x C) / (24 x 365 x P)

Table 48: Summary of Power Generation Potential in Sri Lanka

Total wheat production	2.4 million Tons

Gross residue generation from straws and stalks	3.5 million Tons
Surplus residue generation from straws and stalks	1 million Tons
Power generation potential using only field-based residue	71 MW

4.4.7 Summary – Power Generation Potential of SAARC Member States Using Field-Based Residues

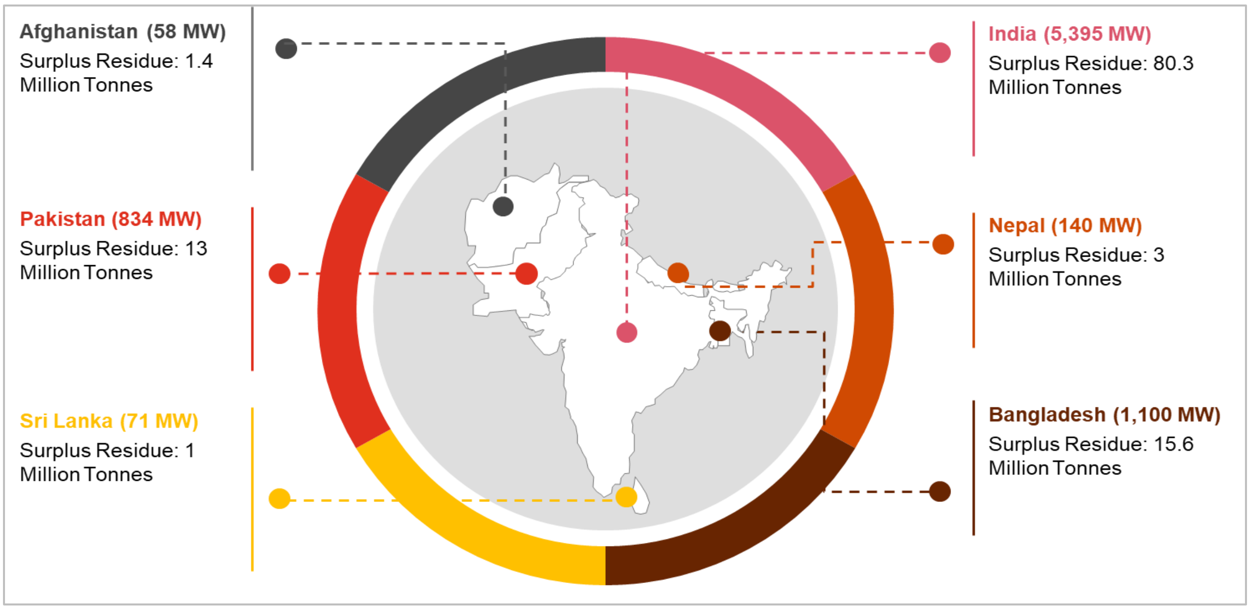
The following table summarizes the power generation potential from rice and wheat crops' field-based residues in the SAARC Member States.

Table 49: Summary of Power Generation Potential in SAARC Member States

Member State	Residue used	Total wheat and rice production (million Tons)	Gross Residue Production (million Tons)	Surplus Residue Production (million Tons)	Total Power Generation Potential (MW)
Afghanistan	Wheat straws	4.2	6.4	1.4	58
Bangladesh	Rice and Wheat straws	38.1	57.2	15.6	1,100
India	Rice and Wheat straws	212.6	319	80.3	5,395
Nepal	Rice and Wheat straws	7.7	11.6	3	140
Pakistan	Rice and Wheat straws	36.3	54.4	13	834
Sri Lanka	Rice straws	2.4	3.5	1	71
Total		**301**	**452**	**114**	**7,598**

The annual energy potential for each Member State have been illustrated below.

Figure 59: Energy Potential in SAARC Member States



The highest energy potential is seen in countries with larger areas and subsequently larger production of crops and residue. India has the highest potential for power generation (5,395 MW), followed by Bangladesh (1,100 MW) and Pakistan (834 MW).

Power generation potential in Maldives and Bhutan have been excluded from this study due to the limited number of crops grown in the country, by virtue of which their residue potential is negligible, and by extension the energy generation potential. The power generation potential is also affected by their tough geographical landscape and difficulties in collection and aggregation of any probable residue.

4.5 Potential Energy Use

Figure 60: Potential Use of Energy Generated

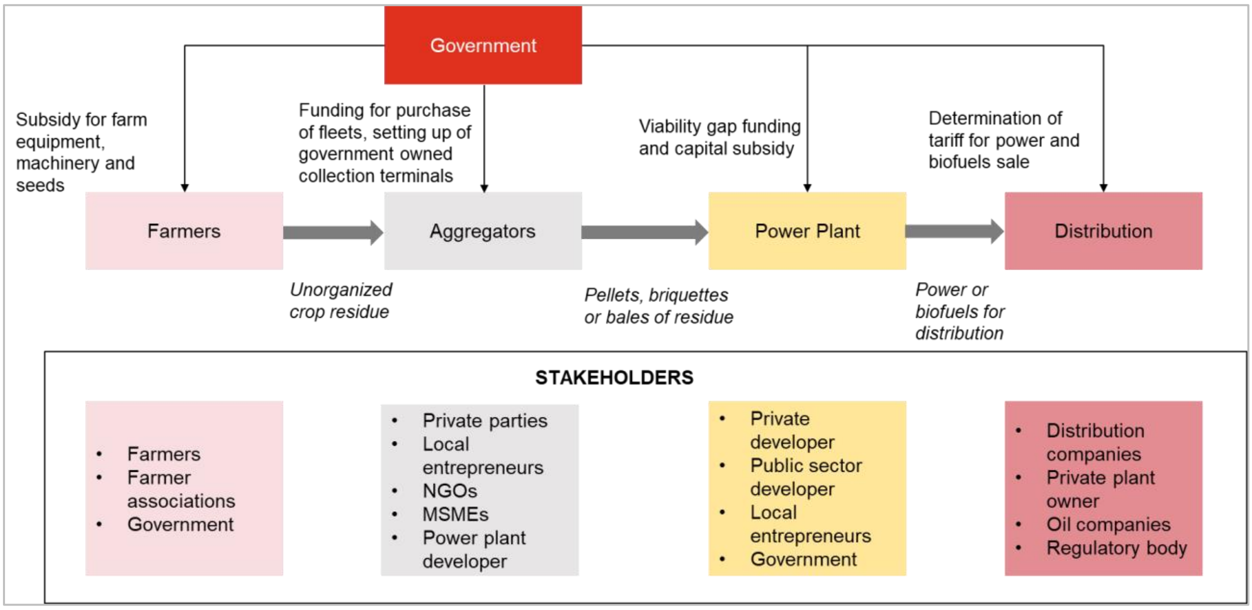
Decentralized electricity distribution	To provide off-grid decentralized electricity to rural households Electricity to power small shops and commercial applications like printing, xerox etc. Waste heat recovery system to increase efficiency and for captive electricity generation
Heating applications	As a source of cooking fuel in households As a source for domestic heating in colder regions Rural enterprises such as brick making, rice par-boiling, pottery and charcoal making
Sale of by-products	Sale of bio-char to agro-based industries to produce soil nutrients Sale of bio-oil to oil companies to substitute fuels Sale of ash to cement manufacturers and brick making companies

4.6 Business Model for Energy Generation Using Crop Residue

The most common business model comprises of five key bodies: farmers, aggregators, power plant developer, distribution companies and the respective government (regional, state/province, central). The farmers harvest their crop and store the residue at their sheds, houses or on farms till the aggregators collect them. The aggregators collect the typically unorganized residue from the farmers at the pre-negotiated base price. In case the farmer is supplying the residue till the collection terminal the transportation cost is paid additionally. The aggregators then take the residue to the collection terminals where the residue is processed into their desired form for the gasifier: pellets, briquettes or bales. The residue is then stored under controlled temperature and moisture conditions until delivered to the plant. The power plant developers choose to store the annual supply of residue in these collection terminals to use throughout the year and save storage space at the plant site. The collection terminals must have enough space and provisions to store a yearlong supply of residue in the required condition. Once delivered to the plant the residue is fired in the gasifiers to create energy in the form of electricity, heat or bio-fuels. The power is then sold to the Distribution Companies (Discoms) for sale through the grid or sold off-grid to rural households. The bio-fuels are sold to oil or transport companies.

The government plays an important role in all the stages, right from sowing to sale of end products. To the farmers, the government provides subsidy to purchase farm equipment, machinery, seeds, fertilizers etc. The aggregators and collection centers may sometimes be government-owned, or the private aggregators approach government for funds to purchase the large fleet required for residue transportation. Different Ministries of respective countries provide support to the power plant developers by way of subsidies in capital cost, introducing favorable policies for exploration of biomass power and setup of power plants, grants and funds. Lastly, the government regulatory bodies determine the power purchase cost for Discoms to purchase the power from developers.

Figure 61: Business Model for Successful Supply Chain



4.7 Success Stories of Using Crop Residue for Energy Generation

This section covers few relevant examples from across the world where crop residue has been used for generating electricity, both grid-connected and decentralized, production of bio-fuels and other allied purposes. The section covers the different ways in which crop residue can be utilized to suit the need of the region based on their availability, technology used and desired end-product. The critical factors that led to the success of each project have also been mentioned for replication in SAARC Member States.

Example 1: Co-firing with biomass at the Edenderry Power Station, Ireland

Background:

The Edenderry Power Station, commissioned in 2000, is a 120 MW peat-fired power plant located in Edenderry, Ireland. In order to reduce the high carbon emissions, the company considered the use of cofiring of biomass along with the peat in the year 2002. Trials were conducted with different biomass materials, like forest derived, agricultural residue and energy crops grown specifically for non-food purposes, to determine their chemical suitability and ability to flow through the existing peat handling and feed systems. The successful trials showed that the plant could fire a mixture of peat and selective biomass and significantly reduce carbon emissions depending on the quantum of biomass used in co-firing. The power station started co-firing of peat and biomass in 2008.

Project details:

The power plant initially launched with a co-firing of 18% biomass in 2008 and progressively increased to it to 30% in 2015 as per the Government of Ireland directive. The quantum of biomass will be further increased to 50% by 2020.

Biomass materials used:

Sawdust, wood chips, willow chips, birch chips, Elephant grass, palm kernels. The biomass chosen had an ash content <5% and was pretreated to form particle size <40 mm.

Figure 62: Carbon Intensity of Co-Firing

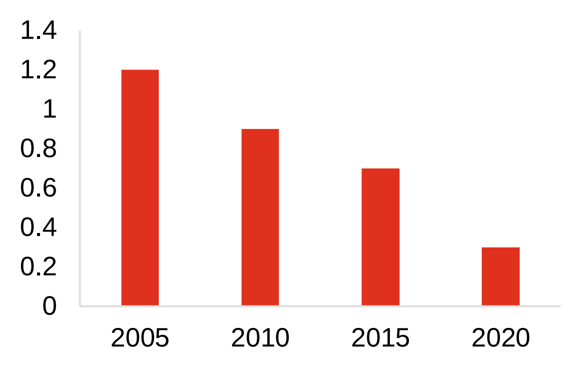
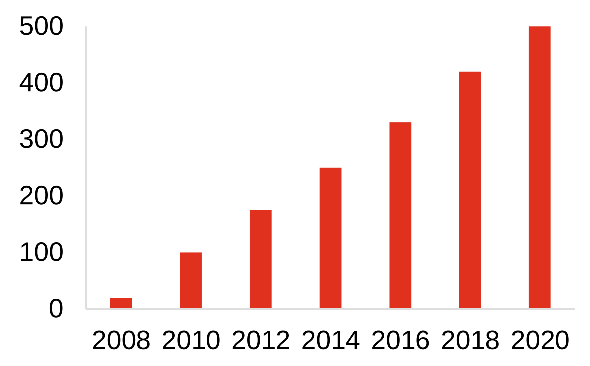


Figure 63: Biomass Usage (000 Tons)



Source: Case Study, Co-firing with biomass at Edenderry power station

Impact of the project:

The project provides an excellent example of the use of biomass along with conventional fuel in combustion-based power plants in order to significantly reduce carbon emissions by replacing significant quantities of fossil fuels with net carbon neutral renewable fuel. Other positive impacts from the project are enumerated below:

1. Meeting the mandate of the Government of Ireland of 30% co-firing of State-owned peat power generating stations by 2015
2. Reduction in carbon emissions from 1.2 million Tons of CO_2/MWh in 2005 to 0.2 million Tons of CO_2/MWh in 2020
3. Use of locally grown willow and birch wood chips along with palm kernels for renewable energy generation for decentralized electricity generation and distribution

Success Factors: Encouraging Public-Private Partnerships for selection and modification of existing power plant for co-firing biomass, and significant reduction in CO_2 emissions

Example 2: Agriculture residue-based biomass power plant in Shandong Shanxian, China

Background:

In December 2006, China developed its first commercial biomass power plant using combustion technology in Shanxian County, Shandong Province. The plant has an installed capacity of 30 MW, which was originally designed for woody fuels only, but was later optimized to run on a variety of different biomass fuels. After 12 years of operation, it is still the best performing mixed-fuel based biomass power plant in China. The power generated from the plant is supplied to the national grid of China for transmission and distribution.

Project details:

The plant employs an advanced HPHT (High Pressure High Temperature) combustion technology for production of electricity. The key attraction of the plant is its ability to process more than 20 different types of fuels. Fuel types include corn cobs, rice husk, wood chips, bark, agricultural residue like straw. The plant consumes around 250,000 Tons of biomass per annum which is supplied locally from a pool of 50,000 farmers, each owning less than 1 acre of land. The farmers deliver the fuel to 8 logistics stations set up by the power plant, all within 30 km radius of the plant. From there on the fuel is transported using trucks to the fuel storage area of the plant. However, the fuels need to be shredded before delivery to the plant. The power plant has an on-site fuel storage capacity of 5-7 days.

Biomass materials used:

Corn cobs, rice husk, wood chips, eucalyptus bark, peanut shells, agricultural hard straws.

Impact of the project:

1. The plant is the first commercial mixed-fuel biomass power plant in China with an ability to process more than 20 different types of fuels.
2. The power plant generates around 200,000 MWh of electricity which is supplied to the national grid for transmission and distribution.
3. The project also provides renumeration to the farmers with small holdings for the agricultural residue they provide, thus aiding economic development of locals.

Success Factors: Social and economic development of farmers by using locally sourced fuel, establishment of a successful supply chain and the ability to process different types of fuels to adapt to harvesting seasons and availability of crops all year round

Example 3: Production of biofuel from agricultural waste in Crescentino, Italy

Background:

Italy commissioned the world's largest cellulosic biofuels facility in October 2013 in Crescentino, Italy. The plant is the first in the world to be designed to produce ethanol from agricultural residues and energy crops at commercial scale using enzymatic conversion.

Project details:

The facility developer, Beta Renewables, formed a strategic partnership with Novozymes which provides the enzymes needed for the ethanol production. The plant uses wheat straw, rice straw and arundo donax (a high-yielding energy crop grown locally) to produce 75 million liters of cellulosic ethanol per year. The polymer that is extracted during the ethanol production process, Lignin, is used at their captive power plant, which generates enough power to meet the facility's energy requirement and any excess energy is sold to the local grid.

Biomass materials used:

Locally sourced wheat straw, rice straw and arundo donax

Impact of the project:

1. The plant is the first and largest commercial facility in the world to produce cellulosic ethanol using agricultural residues only.
2. The facility produces 75 million liters of ethanol every year which is exported to other countries, primarily Brazil
3. The plant also uses the by-product of the process to successfully generate electricity and power the plant operations, thus effectively becoming a zero-waste plant.

Success Factors: Social and economic development of farmers by using locally sourced fuel, use of only agricultural waste for biofuel production and use of by-product for captive power generation.

Domestic success story: Praj Industries in India is in the process of setting up four commercial scale smart bio-refineries to produce and supply second-generation ethanol to Indian companies such as IOCL, BPCL, HPCL and MRPL. The detailed design and engineering work has been completed and equipment offers have been received for two bio-refineries. The plants are scheduled to be operational by FY 2021.

The plants will utilize 500,000 Tons of paddy straw annually and produce 110 million liters of ethanol annually that will be supplied to oil marketing companies

Example 4: Production of decentralized power using rice husk in Bihar, India

Background:

Husk Power Systems (HPS) has installed more than 70 mini-power plants in Bihar since 2007. These mini-power plants were setup specifically for villages off the grid or those connected to the grid but with negligible or unreliable power supply. These projects were setup using financial subsidy from Ministry of New and Renewable Energy (MNRE) to generate power using the available renewable biomass in and around Bihar.

Project details:

HPS has installed over 70 mini-power plants in rural India that use biomass gasifiers to power ~30,000 households across 250 villages. Each power plant has a capacity of 25 kW and serves about 400 households.

Investment:

Each 25-kW biomass gasifier unit incurs a capital cost of approximately USD 25,000. The power plants are installed and operated under different business models as per the need and technical and financial capability of the village/cluster members. The details of different business models used by the company are illustrated in Table 50.

Business model:

HPS has adopted a demand driven approach and quantifies each household's potential demand in watt-hours. The company charges Rs 100 from each household as installation charge, which aids in the project's capital cost and ensures compliance by the users. As most households don't pay tariff the monthly charges are calculated on actuals, based on the appliances to power- generally CFL bulbs, mobile chargers, small TV sets and commercial uses like xerox machines, printers etc.

The company has set up clusters in the range of 20-25 km, with each cluster having about 5-7 plants based on the demand. Each cluster has a cluster level manager who ensures the collection and distribution of rice husk from the farmers to the plants. The husk is collected at village level and transported to the plants using trucks.

The company works on four different business models for rural electrification as illustrated in Table 50.

Table 50: Business Models of HPS

BOOM (Build, Own, Operate and Maintain)	HPS has 100% ownership of the plant HPS builds, installs, operates and maintains the gasifier plants

BOM (Build, Own and Maintain)	HPS builds, installs, owns and provides regular maintenance of the plant for 6 years (contract period) A local entrepreneur manages the daily operation of the plant- fuel collection, generation and sale of energy The local entrepreneur will also invest Rs 2 lakh and pay a monthly maintenance charge of Rs 15,000 At the end of the contract period the ownership of the plant will be transferred to the local entrepreneur
BM (Build and Maintain)	HPS builds, installs and provides maintenance services for the contract period The plant is fully owned and operated by the local entrepreneur investing the complete capital cost Any financial assistance obtained by the plant gets transferred to the entrepreneur HPS charges Rs 15,000 to cover plant AMC, but any non-regular maintenance is charged on actuals
BTM (Build, Train and Maintain)	HPS provides all technology and equipment along with knowledge and training of team HPS also provides regular maintenance under AMC HPS also facilitates monetization of the bio-char and any Government financial aid

Biomass materials used:

Locally sourced rice husks in Bihar

Impact of the project:

1. Each plant with a capacity of 25 kW serves about 400 households and replaces 42,000 liters of kerosene and 18,000 liters of diesel per year
2. Overall the 70 mini-power plants have provided employment and training to more than 300 locals in rural India for operating and maintaining the plants
3. The company also sells the bio-char, which is a by-product of the gasification process, and generates additional revenue for the project
4. The farmers are adequately compensated for the sale of their agricultural waste which has a two-fold impact: provides income source to farmers and deters them from burning the crop residue in the fields

Success Factors: Provision to choose from different business models to suit the needs of the village, set up of clusters for hassle free collection of residue, pre-installation energy audits of each household to determine appliances used and their demand, Social and economic development of farmers by using locally sourced fuel, efficient use of the by-product for additional revenue generation

Example 5: Biomass Power Project at Kalpataru Energy Venture Pvt Ltd in Rajasthan, India using mustard crop residue

Background:

Kalpataru Energy Venture Private Limited (KEVPL) has implemented an 8 MW biomass-based power generation plant utilizing crop residue in the state of Rajasthan to generate electricity. The power plant, commissioned in July 2003, utilizes crop residue generated from the mustard crop considering that the state has abundant availability of the crop and the residue generated after harvest does not have much utility. The energy generated is exported to the state grid for distribution to end-users.

Project Details:

Table 51: Technical Details of KEVPL

Parameter	Value
Plant Capacity	8 MW
Boiler Capacity	40 TPH
Boiler Steam Pressure	45 kg/cm^2
Boiler Steam Temperature	425°C
Boiler make	Thermax
TG make	Shin Nippon

Source: CDM, Project Design Document, KEVPL

Investment:

The Company has incurred a capital cost of approximately USD 5 million for the installation of the 8 MW plant, at USD 625,000/ MW in Bayana, Rajasthan.

Selection of site:

The plant has been set up in Bayana Tehsil in Bharatpur district in Rajasthan, India. The area was chosen based on biomass assessment studies carried out by The Energy Research Institute (TERI), ORG-Marg and the Ministry of New and Renewable Energy (MNRE), Government of India. The studies indicate that the mustard crop residue is abundantly available in the identified area, and it is not suitable for use as cattle fodder or domestic fuel. Around 90% of the residue is burnt in the field each year after harvest season, causing massive air pollution.

Biomass availability:

The biomass assessment studies were carried out by the different institutes in four districts in Rajasthan namely- Bharatpur, Dausa, Karauli and Alwar, covering a total of 37 villages. The studies also included primary interactions with farmers to assess the average area of land holdings, crops grown and their annual yield, harvesting methods and disposal of the crop residue, transportation facilities and the availability of residue stock for the sustainable operations of the plant. It was estimated that the residue produced will be able to power a generation capacity of 8 MW.

The main source of the biomass will be around 25 km of the plant location and a buffer area from 25-50 km will be used for additional sourcing of biomass in case of shortage.

Collection strategy:

The biomass residue will be supplied directly by the farmers to the plant location without the involvement of any middlemen. This will ensure maximum economic benefits to the farmers and timely payments. The farmers will be directly involved in the effective collection, storage and transportation of the residue to the plant location. KEVPL would be required to build strong partnerships with the farmers to ensure regular supply of residue, which can be achieved by entering into a long-term supply agreement.

Plant design:

The total area required for the project was 36 acres, which houses the Boiler-Turbine-Generator (BTG) unit, the fuel storage area, fuel handling system, water handling system, and ash handling system, amongst the other Balance of Plant (BOP) units. The plant has installed a single boiler of 40 tph capacity operating with steam inlet pressure of 45 kg/cm^2 and 425°C temperature. The fuel burning system is a travelling grate stoker with gravity feed system. A travelling grate type boiler has been selected for its flexibility to fire any type of fuel with varying size and high moisture content. An overhead bunker stores the feedstock required for one hour of operation which is attached to the travelling grate for fuel inlet.

The water handling system comprises of cooling tower, make-up water, de-mineralization (DM) plant, feed-water makeup and miscellaneous requirements. The total water required for the project is 1,500 m^3/day.

The BOP consists of the fire-fighting system, compressed air system, ash handling system, electrical system, generator panels and other electrical systems, 33 kV substation and switchyard.

The power is generated at 11 kV, which is stepped up to 33 kV for synchronization and transmission. The power is exported to the Bayana grid sub-station, located at 10 km from the project site.

Biomass price:

The biomass is transported to the project site by the farmers without using any middlemen or aggregators. The price of the biomass is calculated from farm to gate and is directly paid to the farmers. The quantity and cost of the residue for the years 2014-2016 has been shown below.

Table 52: Biomass Procurement Price for KEVPL

Year of Procurement	Quantity of Biomass Procured (Tons)	Total Cost of Biomass at Factory Gate (USD)	Cost of Biomass at Factory Gate (USD/ Tons)
2014	88,994	3,269,011	37
2015	108,889	3,564,780	33
2016	79,884	2,105,945	26
Weighted average price of biomass			**32**

Source: Biomass Fuel Supply Study, Rajasthan Renewable Energy Corporation Limited, 2017

On average it can be estimated that the company spends ~USD 32/Tons for procurement of biomass from the farmers.

Mode of implementation:

The project was implemented under the umbrella of the Clean Development Mechanism (CDM) program. Under the program mechanism, KEVPL was registered as a CDM project activity under the UNFCCC to avail the carbon credits against the reduction in CO_2 by the project. The project considered a crediting period of 7 years, over which the project generated 333.21 million Units of power which was exported to the grid for sale. This resulted in CO_2 emission reduction of 314,179 Tons in 7 years. KEVPL was issued the equivalent Certified Emission Reduction units (CERs) which were traded in emissions trading schemes for monetary benefits.

Barriers in implementation:

a) Financial barriers:

The project faced significant financial barriers on account of a) high upfront cost, b) technological issues on using mustard crop for energy generation, c) no prior experience of promoter in implementation power generation using mustard crop residue and d) apprehension over cash flow

The project was registered as a CDM project activity with a renewable crediting period to ensure cash flows and acquire funding from Financial Institutions. The project has also signed a long-term Power Purchase Agreement (PPA) for 20 years with Rajasthan Rajya Vidyut Prasaran Nigam Limited (RVPN) for sale of net energy generated. The project thus secured two assured revenue streams. The project also secured favorable loan repayment terms on account of these assured revenue streams.

b) Technological barriers:

The project envisaged using mustard crop residue as a fuel for power generation which contains higher percentage of alkali salt in the ash generated, which leads to clinker formation in the furnace. The project addressed these issues by a) maintaining low furnace temperature, b) controlling the carryover of combustibles from the furnace to avoid secondary combustion, c) frequent removal of ash from the furnace and d) use of modern boiler technology to maintain high pressure

c) Operational barriers:

The biggest operational risk envisaged by the project was the supply of fuel over the lifetime of the project. This was ensured by capacity building and knowledge sharing with the farmers to deter them from burning of the residue in the fields. The farmers were assured monetary returns for the residue by signing of long-term supply agreements. KEVPL has also employed local labor from the nearby villages for O&M of the plant, thus building trust in the farmers and ensuring sustenance of the project.

Sale of Power:

The project has signed a long-term PPA for 20 years with Rajasthan Rajya Vidyut Prasaran Nigam Limited (RVPN) for sale of net energy generated.

Table 53: Generation Profile of the Project

Particular	Unit	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13
Plant Capacity	kW	8,000	8,000	8,000	8,000	8,000	8,000	8,000
PLF	%	85%	85%	90%	90%	95%	95%	95%
Maximum operating period (365 days)	Hours	8,760	8,760	8,760	8,760	8,760	8,760	8,760
Effective operating period (330 days)	Hours	7,920	7,920	7,920	7,920	7,920	7,920	7,920
Gross power generated	million units	53.86	53.86	57.02	57.02	60.19	60.19	60.19
Auxiliary consumption	%	12%	12%	12%	12%	12%	12%	12%
Auxiliary consumption	million units	6.46	6.46	6.84	6.84	7.22	7.22	7.22
T&D losses	%	2%	2%	2%	2%	2%	2%	2%
T&D losses	million units	1.08	1.08	1.14	1.14	1.20	1.20	1.20
Grid losses (equivalent to T&D losses)	million units	1.08	1.08	1.14	1.14	1.20	1.20	1.20
Net exported power	**million units**	**45.24**	**45.24**	**47.90**	**47.90**	**50.56**	**50.56**	**50.56**

Source: CDM, Project Design Document, KEVPL

Impact of the project:

Environmental benefits: The project saw a reduction in crop residue burning in the proposed area with a reduction in GHG emissions. The project saw an annual average emission reduction of 44,882 CO_2e (Tons of CO_2 equivalent). The project also obtained Certified Emission Reduction units (CERs) under the CDM program for an additional revenue stream.

Socio-economic benefits: The project created employment for skilled and unskilled labor in the nearby villages. The local people also learnt how to operate modern technology through efficient capacity building programs. The project also provided high economic returns to the farmers for their supply of mustard crop residue. The project also created business opportunity for local stakeholders like bankers, suppliers, manufacturers and contractors.

Success Factors: Using locally sourced and abundantly available mustard crop residue, significant reduction in CO_2 emissions, generation of CERs, employment of local labor and elimination of middlemen for supply of residue to plant premises.

The following table captures details of some of the small-scale biomass gasification plants operational in India that use alternate crops (apart from rice and wheat stalks) for power generation.

Table 54: Small Scale Installations in India Using Alternate Biomass

Sr. No.	Capacity	Name of plant	Location	Biomass used	Equipment supplier
1	1 MW	Ruchi Soya Industries	Washim, Maharashtra	Soya stalks and waste from soya processing plant	Thermax Limited and Royal Dahlman, Netherlands
2	1 MW	Cummins Cogeneration India Private Limited	Karisalpatti, Tamil Nadu	Coconut shells	Cummins India Ltd
3	1.2 MW	Ankur Scientific Power Plant	Vadodara, Gujarat	Cotton, tur and Castor stalks, and corncobs	Ankur Scientific Energy Technologies
4	2 MW	Vana Vidyut Private Limited	Sivagangai, Tamil Nadu	Wood chips from fast growing trees such as bamboo	Ankur Scientific Technologies Pvt Ltd

Source: Company websites & MNRE

Example 6: Production of Bio-CNG using agricultural waste in Pune, India

Background:

Primove Engineering Pvt Ltd has implemented India's first Bio CNG plant in Pune in the year 2016 which utilizes agricultural waste for energy generation. The Bio CNG is used to power automobiles with the same efficiency as CNG derived using fossil fuels and is marketed and sold under the name AgroGas.

Project Details:

Table 55: Details of Primover Engineering Plant

Parameter	Value
Plant Capacity	5 Tons/day
Energy Potential	GCV of ~52,000 kJ/kg
Capital requirement	~2.3 million USD (16 Crore)
Biomass used	**Primary sugars**: Spent wash, press mud, wasted food grains
	Semi cellulosic biomass: Rice straw, wheat straw, soya trash, napier grass
	Cellulosic biomass: Cotton straw, sugarcane bagasse, bamboo shoots

Parameter	Value
Utilization of gas	• 70 buses (70 kg/fill) or • 500 cars (10 kg/fill) or • 800 autorickshaws (6 kg/fill)

Source: Akshay Urja, MNRE, December 2016 Edition

Production process:

The biomass is fed into a single-stage reactor which is converted to biogas using a Primove patented process. This biogas is a mixture of methane (CH_4), Carbon dioxide (CO_2) and Hydrogen Sulphide (H_2S). The biogas is then purified to remove all impurities to get biomethane and other gases that meet the government standards. The purified biomethane is then pressurized and filled into high-pressure cylinders. The cylinders are then used to fill gas in automobiles at the dispensing stations.

A comparison of AgroGas and other commercially available CNG is shown below:

Table 56: Comparison of AgroGas and CNG

Parameter	AgroGas	CNG
CH_4	Minimum 90%	90%
CO_2	Maximum 4%	Maximum 3.5%
H_2S	16 ppm	16 ppm
Moisture	5 ppm	5 ppm
Filling pressure	220 bar	220 bar

Impact of the project:

1. The gas has similar properties as fossil-fuel CNG and displaces the use of CNG effectively
2. The cost of Bio-CNG is less than CNG and will be preferred by consumers
3. The plant also utilizes waste from other food processing industries

Success Factors: Use of only agricultural waste and food processing waste for Bio-CNG production, gas with similar properties as fossil-fuel based CNG is derived and can be directly replaced in automobiles, economically competitive price as compared to CNG

Similar to the above example different international players intend to install Bio-CNG or biogas plants in India using their own technologies. The details of such installations are provided below:

Table 57: Small Scale Installations in India

Sr. No.	Name of Developer	Location	Biomass Used	Products Produced	Status
1	Verbio Vereinigte Bioenergie AG	Sangrur, Punjab	Paddy straw	Bio-CNG: 33,000 kg annually Manure: 45,000 tons annually	Under construction
2	HoSt Bioenergy	Gurdaspur, Punjab	Paddy straw	Biogas- 24,000 m^3/day	Planning stage

Source: Newsletters and Company websites

4.8 Models for Implementation of Projects

The typical models under which power projects are implemented are shown below. SAARC Member States are seeing increasing participation from the private sector in the implementation of bioenergy programs. The countries are also offering a wide range of incentives for foreign investors keen on setting up of projects in the South Asian regions.

Table 58: Models for Implementation of Bioenergy Projects

Private	The power plant is constructed by a private party without major capital investment by the government. The project is implemented under the BOO (Build Own and Operate) model wherein the power plant is built and operated by the private developer for the entire lifecycle of the plant. The cost of funding in case of private ownership is highest. The operations cost is the lowest in a privately-owned setup
Public	In a government owned/ public project the power plant is owned and operated by the government authority (state/ provincial or central). The power plant is installed on government owned land or purchased land. The plant is also financed using government funds, grants and subsidies. The cost of funding for publicly owned plants is the lowest and easily available. However, the O&M costs are seen to be higher.
Public Private Partnership	In a PPP based model, the projects are built on BOT (Build Own and Transfer) or DBO (Design Build Operate) basis. In a typical BOT project, the asset ownership lies with the authority and the private party has the long-term right to use the asset and will be responsible for operations and some investment. At the end of the predetermined period the project will be transferred to the authority. The private party obtains its revenue through a fee charged to the government/authority, rather than tariffs to the consumers.
Public Private Partnership	In a DBO project, the government body owns and finances the construction of the power plant. The private sector will design, build and operate the plant to meet certain agreed outputs. The private party will take no financing responsibility and will be paid a sum for the design-build of the project. The projects built under this model acquire financing at lower interest rates and the O&M costs are optimized for higher cost recovery.

4.9 Study of Commercial Aspects of Gasification

Introduction:

The commercial aspects of setting up biomass gasifier power plants in the Indian State of Punjab has been considered for illustration purpose. Punjab is one of the highest producers of rice, wheat and sugarcane in the country. The State is heavily dependent on rice-wheat cropping system and produces a huge quantity of crop residue. The rice stubble is burnt in the fields in the months of October-November within a period of 2-3 weeks for an economical and quick alternative to prepare the fields for the sowing of wheat. The rice straw is also considered a poor cattle feed due to its high silica content. The farmers also complain of very high labor cost to manually remove the straw and stubble from fields. Additionally, due to lack of buyers or very low economic returns for the rice residue the farmers prefer to burn the residue in the farms. The adverse effects of rice residue burning is visible in the Northern parts of India and Pakistan when the smoke from the crop residue burning combines with the fog to produce smog. This smog is known to cause severe breathing issues, health hazards and visibility issues leading to accidents. The pattern is repeated in the months of April-May when the wheat stubble is burnt in fields. If the residues from rice and wheat are managed sustainably for energy production the issue of crop residue burning would be tackled to a great extent along production of off-grid electricity for supply to rural areas.

Methodology:

The rice and wheat production for the year 2018-19 in all the districts of Punjab has been considered for the study. The gross residue generation and surplus residue generation have been computed for all the districts to formulate an implementation plan.

Table 59: Rice and Wheat Production in Punjab

Sr. No.	District	Rice Production (000 Tons)	Wheat Production (000 Tons)
1	Amritsar	801	920
2	Barnala	846	609
3	Bathinda	1,137	1,345
4	Faridkot	712	619
5	F.G. Sahib	517	454
6	Fazilka	560	977
7	Ferozepur	1,238	1,011
8	Gurdaspur	944	876
9	Hoshiarpur	417	620
10	Jalandhar	1,073	861
11	Kapurthala	765	523
12	Ludhiana	1,721	1,291
13	Mansa	767	890
14	Moga	1,219	908
15	Mohali	152	248
16	Shri Mukatsar Sahib	1,087	1,108
17	Pathankot	136	165
18	Patiala	1,373	1,223
19	Ropar	212	327
20	Sangrur	2,019	1,599
21	S.B.S Nagar	354	385
22	Tarntarn	1,086	871
Total		***19,136***	***17,830***

Source: Agricultural Department of Punjab, 2019

The total annual crop production of Punjab for rice and wheat is 36,966 Thousand Tons, which is 18% of India's production. The total gross residue and surplus residue potential from both, rice and wheat have been computed below.

The power generation potential from these crops have been computed as follows:

Annual power generation potential = (Total Surplus crop residue) x (Collection Efficiency)/ (365 x 24 x P)

Where P= Tons of biomass required to produce 1 MW of electricity

The collection efficiency has been considered at 75% of the surplus potential on a conservative scale. The collection efficiency is determined by the distance of the collection centers from the nearby fields and the price compensation provided to the farmers. Shorter the distance and higher the compensation, higher will be the collection efficiency.

Table 60: Power Generation Potential of Punjab Using Only Farm Residue

Crop	Production (000 Tons)	Residue Type	RPR	Gross Residue (000 Tons)	Surplus Residue (000 Tons)	Biomass Consumption Ratio (P)	Power Generation Potential (MW)
Wheat	17,830	straw	1.5	26,745	5,884	1.4	360
Rice	19,136	straw	1.5	28,704	8,037	1.2	573
Total	**36,966**			**55,449**	**13,921**		**933**

The total power generation potential for Punjab is calculated to be 933 MW, of which 573 MW can be generated from rice straw residues and 360 MW from wheat straw residues. However, given the complementary nature of these two crops' harvesting periods it is recommended to install power plants of total 573 MW only which would primarily operate on rice-based residues in the months of November-April and on wheat-based residues in the months of May- October. This will ensure that the residues from both the crops are fully utilized and not stored for longer durations which will degrade the residue and affect the energy generation potential. By installing lower capacities of biomass-gasifier plants the capital cost of installation will reduce significantly.

Technology selection:

Biomass gasification technology has been chosen for power generation owing to its ability to work with a large range of residue type and size and wide operational range that can be scaled up from smaller capacities at a village level installation to larger capacities at a regional or zonal level.

Collection Centers:

The collection and storage of adequate crop residue is the most critical element of the biomass plants success. Based on the geographic distribution of the rice production it is recommended to set up multiple collection points in different districts. The collection centers have a capacity to store between 5,000 Tons-10,000 Tons of rice husk and straw residue. It is imperative to have these collection centers within 20 km of nearby farms to minimize cost of transportation.

Table 61: Suggested Collection Centers for Residue Collection and Storage

Region	Districts	Residue that can be stored (75% collection efficiency)	Residue that can be stored (100% collection efficiency)
North	Amritsar, Gurdaspur, Hoshiarpur and Pathankot	723,000 Tons	964,000 Tons
East	Fatehgarh Sahib, Mohali, Patiala, Ropar and S.B.S. Nagar	844,000 Tons	1,125,000 Tons
West	Faridkot, Fazilka, Forezepur and Shri Muktasar Sahib	1,447,000 Tons	1,929,000 Tons
South	Bathinda, Mansa and Sangrur	1,266,000 Tons	1,688,000 Tons

Region	Districts	Residue that can be stored (75% collection efficiency)	Residue that can be stored (100% collection efficiency)
Central	Barnala, Jalandar, Kapurthala, Ludhiana and Moga	1,748,000 Tons	2,331,000 Tons
Total		**6,028,000 Tons**	**8,037,000 Tons**

Cost of residue:

The cost of residue will depend on the source of purchase and the transportation costs. The straw-based residue can be procured from farmers directly using local aggregators and rice husks from rice mills. The cost of procuring from farmers and mills is in the range of USD 43/Tons- USD 57/Tons. The Central Electricity Regulatory Commission has determined a base price of USD 54/Tons for rice and wheat-based crop residues. The same base price has been considered for development of model.

Size of plant:

The economic viability of biomass gasifier below 10 MW is not sustainable. Beyond this capacity, the logistics of handling the residue becomes increasingly difficult. It is recommended to implement biomass-gasifier plants of 10 MW each in different locations in the State to take advantage of lower transport cost and local labor for plant operations.

Sale of power:

The power generated from the power plants can be sold to the consumers by connecting to the grid. With 100% household electrification achieved in Punjab even the rural houses have an electricity connection, which will add substantially to the energy demand of the State. Decentralized biomass gasifier plants can provide the solution for meeting the rising energy demands from these rural households.

Commercial model for 10 MW biomass gasifier power plant:

The commercial aspects of setting up of a 10 MW biomass gasifier power plant has been considered for illustration. The plant operations are majorly dependent on the availability of adequate biomass supply, transportation costs and capital cost of installation. The equity payback period for installation of such biomass gasifier plant has been calculated under various scenarios. The payback period is based on the following assumptions:

Table 62: Assumptions for Setting up of 10 MW Biomass Gasifier Plant

Particular	Unit	Value	Rationale
Power plant			
Capacity	MW	10	Single power plant
Auxiliary consumption	%	10	As per CERC RE Tariff Regulations
PLF	%	85%	As per CERC RE Tariff Regulations
Useful life	Years	20	As per CERC RE Tariff Regulations
Project cost			
Capital cost	USD/MW	846,970	Before subsidy for biomass gasifier plants
		632,685	After subsidy for biomass gasifier plants
Financial assumptions			
Debt	%	70	

Particular	Unit	Value	Rationale
Equity	%	30	
Return on Equity (for entire useful life)	%	17.60	As per CERC RE Tariff Regulations
Interest rate (WC Loan)	%	11.4	As per CERC RE Tariff Regulations
Interest rate (LT Loan)	%	10.4	As per CERC RE Tariff Regulations
Income tax	%	30	As per CERC RE Tariff Regulations
Discount rate	%	10	As per CERC RE Tariff Regulations
Depreciation rate	%	5.28	For first 13 years
		3.05	From 14th year onwards
Fuel related assumptions			
Biomass base price (inclusive of transport)	USD/Tons	33	For rice and wheat straw-based residue
	USD/Tons	43	For rice and wheat briquettes
Long-term biomass price escalation	%	1.5	
Specific fuel consumption	kg/kWh	1.3	For rice and wheat straw-based residue
	kg/kWh	1.1	For rice and wheat briquettes
Operation and maintenance			
Annual O&M expenses	USD/MW	70,000	As per industry standards
Long-term O&M escalation	%	3	
Revenue assumptions			
Levellized tariff	USD/kWh	0.0825	The tariff has been fixed to compete with other sources of renewable energy sources so that the plant remains commercially viable
Long-term tariff escalation	%	1.50	Escalated at the same rate of biomass procurement price to maintain commercial viability

Source: CERC, RE Tariff Regulations for FY 2019-20

Capital cost:

The capital cost of USD 846,970/MW has been assumed as per guidelines of the Central Electricity Regulatory Commission (Terms and Conditions for Tariff determination from Renewable Energy Sources) for FY 2019-20 (CERC Regulations) for biomass gasifier plants. A capital subsidy of USD 214,285/MW is provided by the Ministry of New and Renewable Energy (MNRE) which further reduces the capital cost of installation to USD 632,685/MW. In the base case, the project cost has been considered without application of subsidy

Financial assumptions:

A Debt: Equity ratio of 70:30 has been considered as per industry standards. Cost of funds has been anticipated at 10.4% and a discount factor of 10% has been considered.

Fuel related assumptions:

The fuel cost of USD 33/Tons with an escalation of 1.5% has been considered for rice straw that can be locally sourced from farmers located within 20 km of the power plant. The fuel cost is inclusive of the base price, transportation to plant site and loading and unloading charges.

Operation and maintenance:

The O&M cost has been considered at USD 70,000/MW with an escalation of 3% over the useful life of the project.

The typical commercial details of the 10 MW biomass-gasifier plant using rice straw as feedstock have been illustrated below to evaluate the viability of a single power plant. If found financially viable the same can be replicated in other districts of Punjab using a similar model of implementation.

Table 63: Commercial Details of the Commercial Model for 10 MW Biomass-Gasifier Plant

Particular	Unit	Without Capital Subsidy	With Capital Subsidy
Capital Cost	USD million	8.47	6.33
Debt	USD million	5.93	4.43
Equity	USD million	2.54	1.90
First year: Fixed cost (A)	USD/kWh	0.035	0.029
First year: Variable Cost (B)	USD/kWh	0.048	0.048
First year: Total tariff (A+B)	USD/kWh	0.08	0.08
First year: Revenue	USD million	5.53	5.53
Levellized tariff for 20 years	USD/kWh	0.0825	0.0825
Debt repayment period	Years	14	14
Breakeven period	Years	7	4

The equity breakeven period for a single biomass-gasifier project without capital subsidy from government is ~7 years. This period can be reduced by 3 years with a 25% capital subsidy. The most critical element in the determination of tariff is the biomass procurement cost. This cost can be greatly reduced by signing annual fuel procurement contracts with the farmers or farmers' associations. By doing so the farmers will be assured of a fixed cost for their residue each year and will proactively reduce the burning of residue in-situ. The tariff is also largely affected by the O&M costs of the power plant. The O&M cost includes the annual maintenance charges as well as labor cost. By way of capacity building and knowledge transfer skilled local labor can be employed for each power plant. By employing local labor, the outsourcing costs can be eliminated, and O&M costs can be reduced greatly.

Effect of using briquettes instead of rice straw:

The rice/wheat straws can be converted into high density briquettes using a briquetting machine (details available in Section 5.1.1) which can then be used as feedstock to the gasifier. The use of such briquettes will have an increase in the biomass procurement price as described in the assumptions set in Table 62, with a proportional decrease in the specific fuel consumption (as the briquettes have higher bulk density). Alternatively, a developer may wish to procure straws from the farmers or aggregators and install briquetting/ pelletizing machines inside the facility and produce briquettes/pellets. However, this would result in additional capital investment and manpower requirement. For the purpose of the model we have assumed that the briquettes are procured directly from the aggregator at a higher price.

Table 64: Commercial Details of the Commercial Model for 10 MW Biomass-Gasifier Plant Using Briquettes

Particular	Unit	Without Capital Subsidy	With Capital Subsidy
Capital Cost	USD million	8.47	6.33
Debt	USD million	5.93	4.43
Equity	USD million	2.54	1.90
First year: Fixed cost (A)	USD/kWh	0.035	0.029
First year: Variable Cost (B)	USD/kWh	0.052	0.052
First year: Total tariff (A+B)	USD/kWh	0.08	0.08
First year: Revenue	USD million	5.53	5.53
Levelized tariff for 20 years	USD/kWh	0.0825	0.0825
Debt repayment period	Years	14	14
Breakeven period	Years	11	6

When compared to the commercials of energy generation using rice and wheat straws as feedstock, is it seen that the breakeven period increases by 4 years (without capital subsidy) and by 2 years (with capital subsidy). This is seen because the price of biomass procurement is increased, but the tariff has remained constant to compete with other sources of renewable energy sources so that the plant remains commercially viable.

Given the success of a single biomass-gasifier power plant the model can be replicated in the other districts to explore the full potential of the crop residue generated. The following cluster-wise implementation plan is recommenced for Punjab to cover all the districts.

Table 65: Cluster-Wise Implementation Plan for Punjab State

Particular	North	East	West	South	Central
Number of 10 MW biomass-gasifier power plants	7	8	14	12	17
Total cluster-wise installation capacity	70	80	140	120	170
Surplus Residue to be stored (75% collection efficiency)	723,000 Tons	844,000 Tons	1,447,000 Tons	1,266,000 Tons	1,748,000 Tons
Capital Investment (million USD)	58	68	117	102	141

With a cluster-wise decentralized implementation of biomass gasifier plants the logistics can be handled efficiently. It is recommended to sign fuel procurement contracts with the farmers to ensure availability of residue and sustainability of the projects.

5 Alternate Uses of Crop Residue

The previous sections cover the large-scale applications of crop residues for energy generation using suitable technologies in the SAARC region. However, in conditions where large scale deployment of energy generation solutions is not viable, alternate usage of this surplus crop residue must be identified. This section covers the different small-scale applications of crop residues which can be deployed in inaccessible areas or areas with lower potential of residue generation. The section also covers the possible effect of advanced mechanized farming techniques on the quality and quantity of crop residue in the SAARC region.

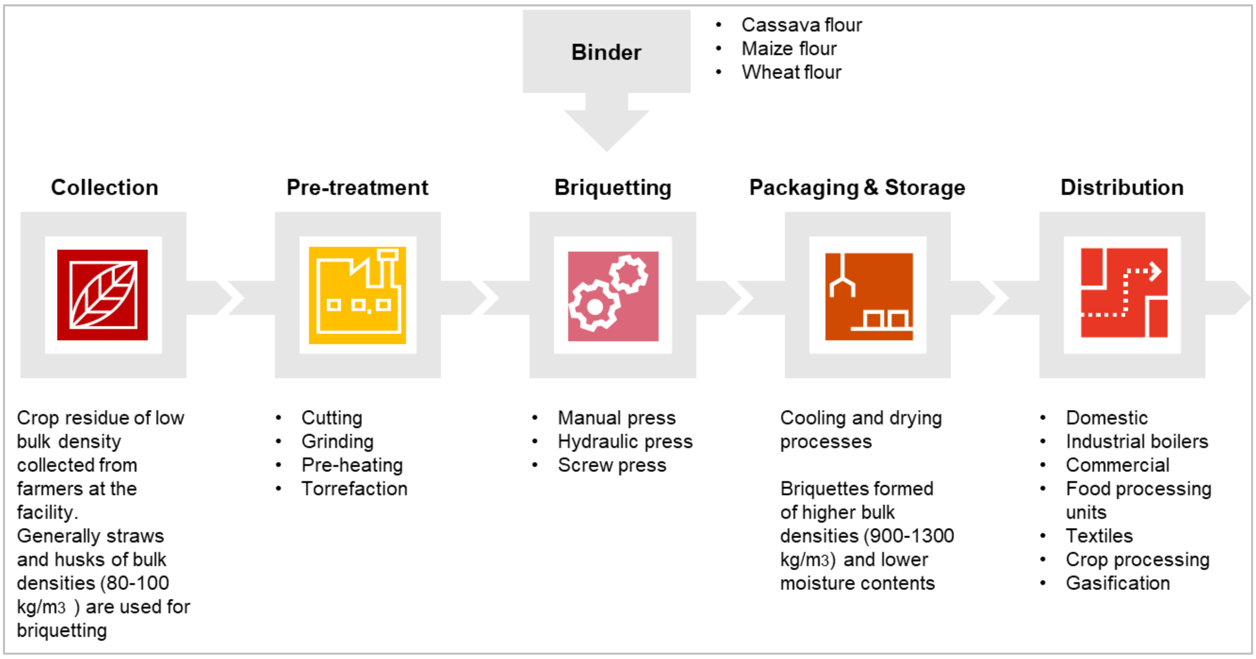
5.1 Small Scale Applications of Crop Residue

5.1.1. Briquetting

Introduction: Briquetting is the process of compacting agricultural residues and other wastes to products of higher densities. The process converts crop residues like straws and husks with lower bulk density (80-100 kg/m^3) to higher bulk density briquettes (900-1300 kg/m^3). Depending on the type of residue used, its moisture content, method and procedure used to prepare these briquettes, they can be used as a fuel for cleaner burning. The briquette machines can be operated by local entrepreneurs or farmer associations to produce products that will replace firewood in rural households or be sold in the market, the production and sales of which will aid in farmers' incomes.

Process of implementation:

Figure 64: Biomass Briquetting System



The steps of briquette making and popular methods/technologies used are elaborated below:

Collection: The surplus crop residue that is not utilized towards energy generation purposes can be collected at village/district levels to be converted into briquettes. Briquetting machines can be installed by local entrepreneurs, small businessmen or farmer associations based on the scale of operations and quantum of residue available.

Pre-treatment: Different types of residue can be used for briquetting which have diverse properties- size, moisture content, heating value, chemical composition etc. Hence some pretreatment is essential to ensure suitable briquette production. The pretreatment processes involve drying of biomass to remove excess moisture, reduction in size using grinding and cutting methods, pre-heating the biomass (not more than 300°C) to loosen fibers and soften the biomass for easier pressing. Generally, the size of the biomass is reduced to 6-8 mm, with a moisture content less than 10% with a powder component of 10-20% depending on the type of residue.

Briquetting: Different types of presses may be used depending on the scale of operations, type of residue and capital expenditure required. Generally, for small scale operations a manual press is employed, which consists of simple designs such as hand-powered screw extruder, lever arm briquette press, car jack briquette press. A screw press is used when the biomass is extruded continuously by a screw through a taper die. A hydraulic press is used for large scale operations and work effectively on tougher residue too. In most cases a binding agent is also added to the residue to aid fastening of particles.

Packaging and storing: The briquettes formed in the process are cooled using a conveyor belt before storage. Once cooled they are stored length-wise in a cool and dry place until transported.

Distribution: Briquettes find use in rural households as a substitute for firewood, along with commercial and hospitality applications such as grilling, water and space heating. They can also be used in industrial boilers for production of heat and steam for electricity generation. Other small-scale applications that use briquettes are crop and spice drying, ceramic production, textiles, tea and coffee processing units.

These briquettes with higher densities provide a higher heat content with less smoke when burnt. They also burn slower than firewood and last longer. They are also easier to transport and distribute through different channels.

Success story: Biomass Briquettes using forest and farm wastes

Rural Renewable Urja Solutions Pvt. Ltd has implemented a biomass briquetting plant in Kotdwara, Uttarakhand, India for the utilization of forest residues, agricultural wastes and industrial wastes. The plant uses 60% forest residues like pine needles, 30% sawdust and 10% agricultural residues from nearby fields. The project was set up by private company which employs women self-help groups in the collection and delivery of these residues to the plant facility. The pine needle and agricultural residue collectors are paid a fixed cost of INR 1000/Tons (USD 14.3/Tons), and the manufactured briquettes are sold to institutions and industries like brick kilns, industrial boilers, restaurants, schools, ashrams, cafeteria, and school hostels, who primarily use it as an alternative to coal or LPG for their requirement.

Table 66: Project Details and Commercials of Rural Renewable Urja Solutions Pvt. Ltd.

Parameter	Description
Plant Capacity	10000 Tons per annum
Composition of raw material	60% pine needles, 30% sawdust and 10% agricultural wastes
Capital cost	INR 1.3 crores (USD 190,000)
Briquette density	>650 kg/m^3
Calorific value of briquettes	~3900 kCal/kg
Benefits	1.3 kg of briquettes can replace 1 kg of coal 3 kg of briquettes can replace 1 kg of LPG use
Customers	Industrial boilers, Brick kilns, hotels and canteens, schools that run mid-day meal programs
Cost of briquettes	1 Tons of briquette for LPG replacement is sold at INR 6,000 (USD 86) 1 Tons of briquette for coal replacement is sold at INR 3,950 (USD 56)

Parameter	Description
GHG emissions prevented	15,000 TCO_2e
Carbon credits	Carbon credits generated by sale of briquettes are sold to MY CLIMATE company

Source: Access to Clean Energy, Winrock International India

Benefits:

The project generates 542 against replacement of coal and 382 against replacement of LPG per ton of briquettes. MY CLIMATE, a Switzerland based agency has entered into agreement with RRUSPL to buy the carbon credits generated by the project. MY CLIMATE in turn sells these carbon credits to the air travelers who want to reduce their carbon footprint. With this arrangement the project contributes renewable energy generation and empowerment of rural population and reduces the carbon footprint of global users. The usage of pine needles for briquette making purpose has also reduced the forest fires by 50% in Lansdowne area.

5.1.2. Small Scale Gasification Applications

Introduction: Small scale gasifier plants of typical capacity 100 kW- 2 MW are gaining popularity in rural areas of South Asia. These systems are usually installed to utilize smaller quantum of biomass more effectively, near the production source and demand centers in order to shorten transport distances and reduce costs. The syn-gas produced from the gasification process is supplied as fuel to internal combustion engines and power generators to produce electrical output. Additionally, the heat from the syngas is also captured to provide thermal output (steam for process plants). These systems find applications in small businesses like grain mills, cold storages, welding workshops, irrigation pumps, spice drying, ceramic making etc. The implementation of some of these systems, technology utilized, and commercial operations have been captured using success studies below.

Case 1: Kasai Village Gasifier, Madhya Pradesh, India

The Ministry of New and Renewable Energy (MNRE), Govt. of India has identified un-electrified village fringe areas in three states of Madhya Pradesh, West Bengal and Uttarakhand to implement energy generation programs. A Village Energy Security Program (VESP) was launched by MNRE to identify such villages. Under the program the village Kasai in Betul district, Madhya Pradesh was identified to install a biomass gasifier power project. The project was funded by VESP and implemented and monitored by the District Forest Officials (DFO). A biomass gasifier plant of 2x10 kW capacity, equipped with a diesel set for black start purpose was installed to benefit ~50 households in the village. The day to day operations are handled by the village panchayat.

Table 67: Project Details of Kasai Village Gasifier

Parameter	Value
Plant Capacity	2x10 kW
Black start	Diesel Generating Set
Plant make	M/s Aruna Electrical Works
Biomass used	Locally sourced firewood from nearby forests
Plant components	Gasifier reactor, with screw-based ash extraction system, cyclone, cooling and scrubbing systems, sand bed and fabric filter

Source: Centre for Sustainable Technologies, Indian Institute of Science

The plant operates only in the evening hours to meet the electrical demands of households. During a 5-hour operating period the system generates ~40 units per day and ~1200 units per month. some amount of diesel is used during the initial stabilization period before operating on gas. The biomass is purchased from the farmers at INR 0.5/kg (USD 0.007/kg) and power is provided to each household on a fixed fee basis per month. Apart from meeting the basic energy demand of each household, the system also operates street lights, a flourmill, a water pump and milk-chilling unit.

Table 68: Commercial Details of Kasai Village Gasifier

Parameter	Cost (USD)
Cost of biomass/kg	0.007
Monthly contribution per family	1.71
Total contribution per month	94
Cost of labor	43
Cost of diesel	7.14
Total operational cost	65
Cost of electricity generated (USD/kWh)	0.05
Payback period	4-5 years

Source: Centre for Sustainable Technologies, Indian Institute of Science

Case 2: Biomass usage for thermal application at Starlit Power System, Haryana

Starlit Power System is a manufacturer of Refined Lead, Lead Alloys and Red Lead in Haryana, India. The Company uses diesel in the production processes in melting and lead furnaces. The facility has two reactors for melting, a refining furnace and kiln with a total thermal requirement of 400,000 kCal/hr. The Company decided to utilize green energy for operating the facility to reduce their fuel costs and GHG emissions.

A downdraft biomass gasifier plant was used to provide the thermal output for operating the furnace. The technology was selected to operate on firewood sourced from local farmers. It was found that the gasifier was able to generate a thermal output of 450,000 kCal/hr and could replace at least 60% of the diesel consumption in the DG set in dual fuel mode and shutdown of the Rotary reduction furnace (normal operating case of the plant). The project realized an annual savings of ~ USD 88,000 on replacing diesel with wood using a biomass gasifier.

Table 69: Project Details of Biomass Gasifier at Starlit Power System

Parameter	Value
Supplier	M/s Chanderpur Works
Wood consumption	180 kg/hr
Daily wood requirement	3,520 kg
Price of wood	USD 0.07
Thermal output	450,000 kCal/hr

Source: Biomass Portal, MNRE

Case 3: Arecanut processing units using biomass gasifiers in Assam

The North-Eastern states in India contribute to over 20% of the total national production of Arecanut. These nuts are processed by boiling and drying them and then exported in major processing units located in Rupahi and Howly in Assam. The nuts are first boiled in large open pans for 30-50 mins, after which they are dried in brick-cement frames using bamboo mats. Firewood is lit under vertical partitions for around 12 hours and the nuts are dried on the bamboo mats above at a temperature of 70-75°C. The nuts are further sun-dried for 2-3 days to remove any residual moisture. On an average 100-150 kg of firewood was used to produce 100 kg of Arecanut, of which 60% was utilized in the boiling stage and the rest for drying. The average wood burnt was 115 kg/hr, with an SFC (Specific Fuel Consumption) of 0.70 kg of wood per 1 kg of boiled Arecanut.

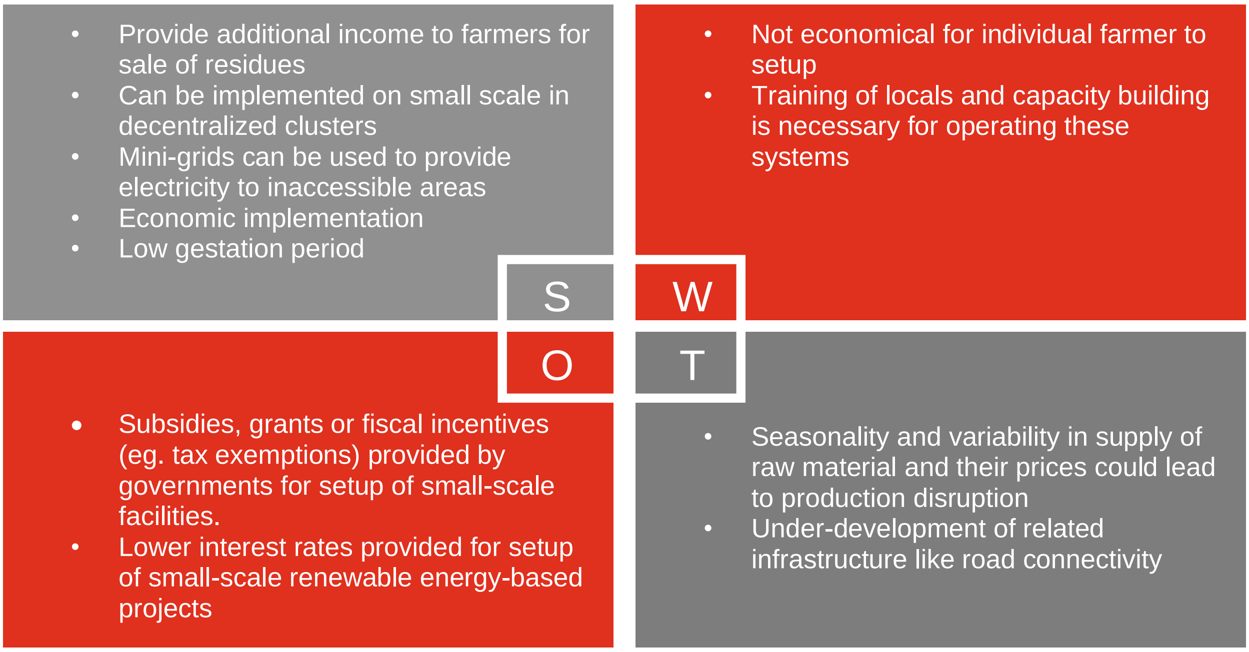
To reduce the fuel consumption and smoke emitted, The Energy and Resources Institute (TERI) has developed biomass gasifier systems for boiling and drying of these Arecanuts in Assam. The gasifiers work on a lower wood consumption (20 kg/hr) for boiling the nuts in the existing boiling pans and use the hot syngas for drying of the nuts. The gasifiers also operate by using the waste Arecanut husks as fuel, thereby reducing fuel costs. The performance and efficiency of the processes have improved by 40-60% as shown below:

Table 70: Performance Improvement of Arecanut Processing Using Biomass Gasifier Plants

Item	Traditional oven	Gasifier system
Number of nuts processed (kg/batch)	140	140
Boiling time required (hours)	2.5	1.0
Fire curing time required (hours)	4.0	3.0
Total fuel consumption (kg/batch)	125	45

Source: Biomass Gasifier Systems for Thermal Applications in Rural Areas, TERI

Figure 65: SWOT Analysis of Small-Scale Applications of Crop Residue



5.2 Applications of Crop Residue in Manufacturing of Products

Various ex-situ management techniques of crop residues like production of fertilizers, compost, mushroom cultivation and usage in paper manufacturing are in practice in the South Asian countries.

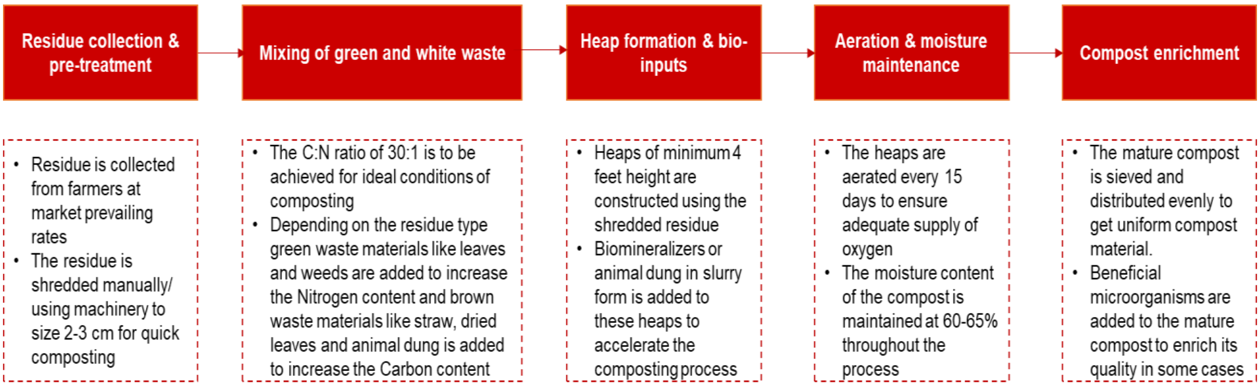
5.2.1. Compost and Fertilizer Making

Introduction: The crop residues left behind after the harvest such as straws, stubbles, stoves and husks can be used as natural fertilizers in the fields to boost the biological and chemical properties of the soil. However, the residue needs composting before being used as fertilizer. The composting method can be of two types- pit composting and aboveground composting, depending on the availability of water, moisture content of soil and temperature of the region. The compost generated is sold to distributors at market prevailing rates.

Case Study: Rice straws are used in the preparation of fertilizers in Tamil Nadu due to its high Carbon (40%) and Potassium (3%) content as compared to other crop residues. The process of compost and fertilizer making is implemented on small scale by farmers in the state by aggregating their residues in a common space generating limited number of fertilizer bags over the year. The compost is then sold to local businesses at market prevailing prices and revenue generated is shared amongst the farmers.

Process implementation:

Figure 66: Biomass Composting Process



Source: TNAU Agritech Portal

Benefits of using crop residue for composting and fertilizing:

1. The crop residues contain the nutrients and beneficial microorganisms that are available in the farm
2. There is improved biological, chemical and physical properties of the soil due to addition of residue-based fertilizer
3. Replacement of chemical fertilizers for cultivation of organic products and maintaining soil fertility and organic matter content
4. Source of income for farmers providing the crop residues and employment for farmers that work in the composting facility

5.2.2. Mushroom Cultivation

Crop residue of few major crops, like rice and wheat, are used in mushroom production in tropical areas. The residues, despite their high moisture content, contain 2-3 times as much protein as common vegetables and amino acids necessary for mushroom cultivation. Wheat and rice straws are used as substrates for cultivation of button mushrooms and straw mushrooms. The straws are mixed with horse manure and hay which are maintained under controlled temperature and moisture conditions for growth of mushrooms. For maximum substrate conversion efficiency, the rice and wheat straws are mixed in equal proportions.

5.2.3. Paper and Pulp Manufacturing

Introduction: Residues that are rich in fibers, like that of rice, wheat, sugarcane and cotton, are predominantly being used for manufacturing of pulp, that can be further utilized to create useful items such as paper, cups, plates, straws etc. Depending on the morphological, anatomical and chemical structure different crops are used for generation of different paper products.

Process implementation and technologies used:

1. **Preparation of the residue**:

Cotton stalks: The stalk bark is removed manually and then cut into small pieces and washed before pulping

Rice and wheat straws: The straws are first cut into smaller sizes of 6-8 cm and passed through a cyclone separator to draw out loose pieces and dust.

Bagasse: bagasse that comes from sugar mills is in a clean state and requires minimal cleaning for pulp production.

2. **Pulp preparation**: The simplest form of pulping is the mechanical process wherein the lignin in the fibers is broken down by wet grinding the residue. This method retains ~95% of the original wood and is the cheapest method of implementation.

A thermomechanical process uses heat and steam to soften the residue before grinding. A chemical pulping process is used for removal of lignin, which results in the highest purity and tolerance to tearing.

3. **Washing and Bleaching**: The pulp is washed to remove any unwanted materials and dirt. In most cases the pulp is then bleached to brighten the color of the paper. Bleaching with chlorine and hypochlorite takes place at normal pressure and at temperatures varying from 20 to 40 ºC.
4. **Fiber preparation before papermaking**: The bleached pulp is then treated before sending to the paper machines. The pulp fibers are squeezed using beaters or refiners to increase the number of fiber bonds and strengthen the paper strength.
5. **Papermaking**: Different types of additives are added to the pulp to improve opacity, smoothness, in penetration etc. depending on the end use. The pulp is then ten sent to the paper machine which consists of three stages: sheet formation, pressing and drying. A suitable paper coating is applied if desired to modify the paper's properties.

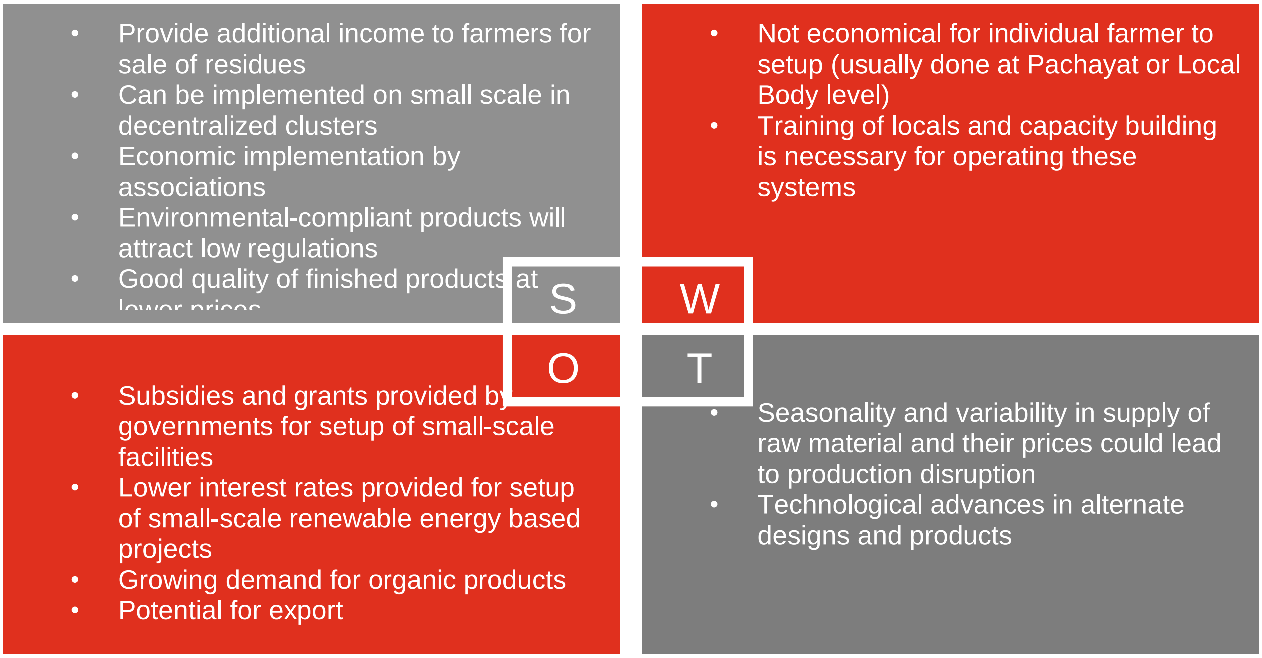
Success story:

Kriya Labs is a Delhi based company have developed a processing technology that utilizes rice straw from the neighboring states to produce pulp, which can then be used to make biodegradable products. It is found that rice straw being high in silica is not suitable for animal fodder, when compared to wheat straw. Hence, most farmers prefer to burn the rice stubble in the fields due to lack of alternate usage. The Company has designed a specialized process of utilizing the rice straws for pulp and paper production and incentivize farmers to not burn straw and generate revenue.

The process is used to segregate the silica and lignin of the rice straw from the usable cellulose (pulp) using natural biodegradable chemicals. The pulp is then dried and molded to form different products such as paper, plates, cups and straws. The facility has a capacity of processing 1-2 Tons of straw per day. The machines can produce 500 kg of pulp from 1 Tons of straw which is then sold for INR 40-45 per kg to manufacturers. The farmers are paid INR 2/kg of straw.

The process is now integrated with small scale machines in the area for multiple decentralized cluster production. The cost of each machine is USD 42,000-50,000 that can process up to 2 Tons of straw per day.

Figure 67: SWOT Analysis of Using Crop Residues in Manufacturing of Useful Products



5.3 Use of Machinery for Crop Residue Management

Introduction: Different machinery used for tackling the issue of crop residue burning and utilizing the straw and stubble in-situ have been developed and deployed in the SAARC Member States. These machines include the Super SMS, Happy Seeder, Paddy Straw Chopper and Balers and Reapers for effectively utilizing crop residues. Some of these machinery aid in utilizing the residue in-situ, while some assist in efficient handling and transportation of the residue for end use.

Technologies/ machinery:

1. **Super Straw Management System (Super SMS):** The Super SMS is a retro-fitted device that can be attached to the rear of a combine harvester that cuts the remaining straw in the fields into smaller pieces and scatters it around the rear of the tractor. The process allows direct sowing of wheat seeds after the rice is harvested. The machine has proven to be a good deterrent to farmers for burning of residue, however the cost of the machine is a major barrier in mass deployment and usage. The cost of a single Super SMS is USD 1,700- 2,000 which is in addition to the purchase of a Combine Harvester that costs around USD 21,000-30,000. The Super SMS machines are not yet available for rental and is being used by very small percentage of farmers with large land holdings only.

2. **Happy Seeder**: The Happy Seeder is a tractor mounted machine that cuts and lifts the rice straws, sows the wheat seeds and distributes the rice straw on top of the soil evenly. Thus, the machine takes care of harvesting, cleaning and sowing of next crop in the same cycle without tilling the field. Each year Happy Seeders are being distributed by the governments in bigger SAARC nations (India and Pakistan) in areas most prone to residue burning and have seen some success. The machines are being supplied to farmer associations as well as individual farmers at subsidized rates to ensure wide spread usage. However, the number of Happy Seeders in the market are proving to be insufficient to cover all the areas. Most farmers with small land holdings are unable to afford

the daily rentals of these machines and continue to burn the residue in-situ.

With increasing impetus of utilizing crop residues in-situ by governments of SAARC nations, the popularity and usage of the Super SMS and Happy Seeder are increasing each year. In case of mass deployment there would be a considerable reduction in the surplus crop residue for alternative purposes. With a reduction in the residue availability the operational viability of biomass gasifier plants would decrease, while on the other the farmers may increase the cost of their residues, further reducing the commercial viability of such plants.

3. **Paddy Straw Chopper**: The machine is used for chopping of all types of straws like wheat, rice, sunflower, maize etc. In a single operation the machine chops the left behind straw and spreads in on the field. A rotovator must be used after the application of a chopper to incorporate this straw into the soil, where it can act as a natural compost. Although the cost of the machine is low (USD 1,400- 3,000) it is not used by most farmers who prefer to utilize manual labor for the purpose of just chopping.

4. **Baler**: The baler is used to compress the raked residues of wheat, rice, sugarcane etc. into compact bales that are easier to store and transport. The use of this machine is generally done by residue aggregators and are purchased to service different clusters before transporting to the storage facility or power plant premises. The baler can make bales of different sizes and shapes to suit the end need and provides an attractive business for farmers/ farmer associations to sell to the power plants. However, the equipment is not economical for purchase of individual farmers (USD 3,500- 4,500).

Modes of implementation: Due to the high cost of the machinery only farmers with larger land holdings can purchase them on an individual usage basis. In most cases these machines are purchased by farmer associations at subsidized rates from the government and then rented out to the farmers in that area during peak harvest seasons. However, due to the scarcity of equipment the daily rental prices are still high for farmers with small land holdings.

Figure 68: SWOT Analysis of Using Farm-Based Machines and Equipment for Crop Residue Management

S
- Efficient usage of residues in-situ
- In-situ usage of residue improve soil quality and restore nutrients
- Aid in storage and handling of residues
- Reduce air pollution
- Reduce the harvesting time of crops

W
- Not economical for individual purchase by farmers
- Some equipment can only be retro-fitted on existing machinery
- Some equipment only takes care of single/few stages of crop harvest and sowing
- Non-availability of spare parts

O
- Increase in production of these equipment
- Increase in subsidies by governments of some countries
- Rising awareness of the alternate uses of crop residue for earning additional income

T
- With increase in usage of these techniques the residue production will reduce, hampering the commercial viability of energy generation plants
- With new technology the older machines may become obsolete or prove costlier to operate

6 Study of Environmental Impact of Crop Residue Burning

6.1 Study of Environmental Effects of Crop Residue Burning

Burning of agriculture residue releases many pollutants, which largely harm the climate, including the greenhouse gases (GHGs), nitrous oxide (N_2O), carbon dioxide (CO_2), and methane (CH_4), particulate matter (PM2.5) and fine particles known as black carbon. Their effects on the climate are variable and complex. The transboundary transport of air pollution in the South Asian region has become an issue of increasing importance over the past several decades. There are two major ways in which biomass burning contributes to climate change:

1. The first is a long-term global warming effect linked primarily to CO_2 emissions and release of GHGs from deforestation and other forms of land conversion during which biomass is burnt and not fully replaced; and
2. The other is a short-term warming effect, which is attributed to the emission of black carbon from the burning of biomass near snow and ice-covered regions.

Particulate matter, PM2.5, affect the respiratory and cardiovascular systems of living beings along with its other environmental effects. The black carbon aerosols have a large impact on the heating, regional circulation and rainfall patterns over the emission regions. The following figures show the PM2.5 and CO_2 emissions in the SAARC region. The particulate matter is measured in micrograms per cubic meter (µg/m^3). Hence, the PM emissions of India and Pakistan are seen to be lower than Bangladesh and Nepal due to their large country sizes.

Figure 69: Particulate Matter (PM 2.5) Air Pollution in SAARC states

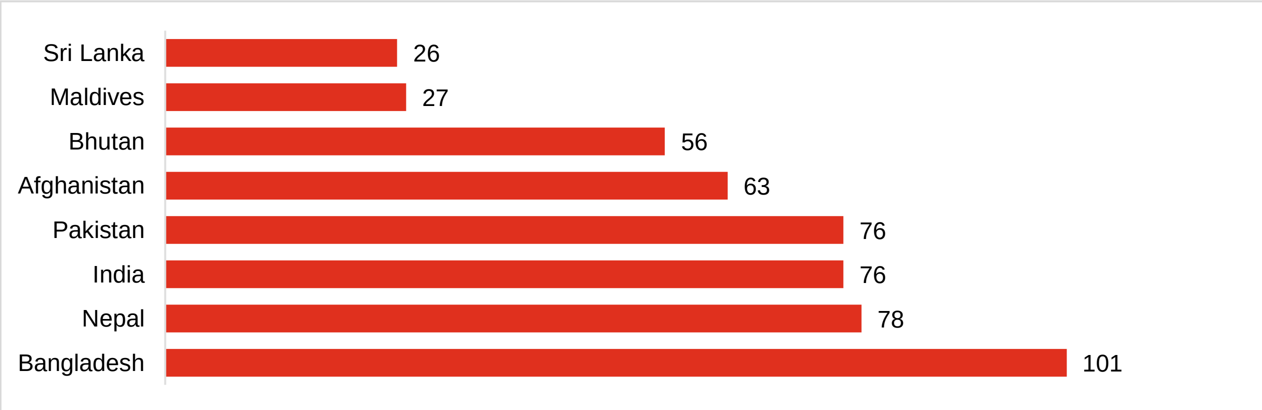
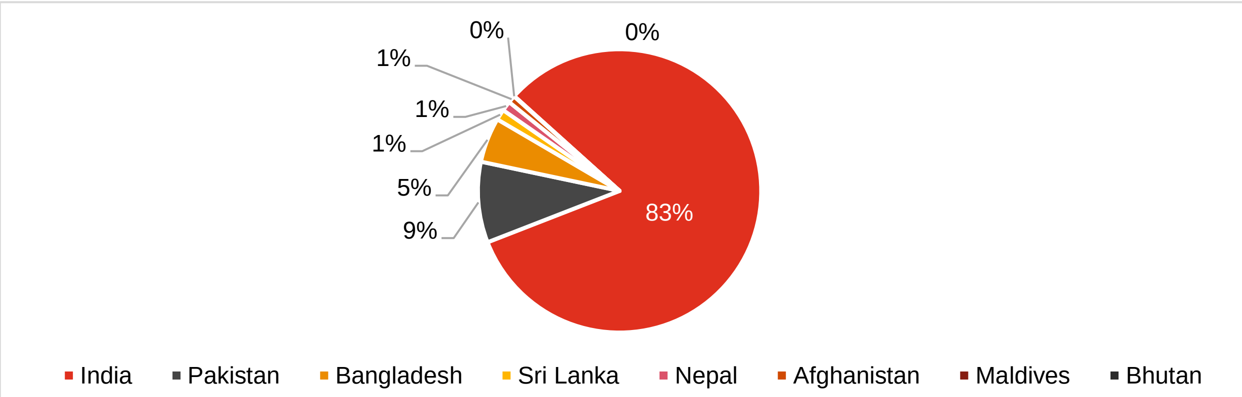


Figure 70: CO_2 Emissions (Mt) in SAARC Member States



The United States Environmental Protection Agency (EPA) has developed the Air Quality Index, or AQI, (formerly known as the Pollutant Standards Index) for reporting the levels of ozone and other common air pollutants. The index makes it easier for the public to understand the health significance of air pollution levels. Air quality is measured by a nationwide monitoring system that records concentrations of ozone and several other air pollutants at more than a thousand locations across the country.

The AQI scale is divided into distinct categories, each corresponding to a different level of health concern. To make it easier for the public to quickly understand the air quality in their communities, EPA has assigned a specific color to each AQI category as shown in the figure below. This color scheme can help to quickly determine whether air pollutants are reaching unhealthy levels in the area. For example, orange means that conditions are "unhealthy for sensitive groups," the color red means that conditions are "unhealthy" for everyone, and so on.

Figure 71: Air Quality Index Categories

AQI level	AQI levels of health concern	Meaning
0 to 50	Good	Air quality is considered satisfactory, and air pollution poses little or no risk.
51 to 100	Moderate	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
101 to 150	Unhealthy for sensitive groups	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
151 to 200	Unhealthy	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
201 to 300	Very unhealthy	Health alert: everyone may experience more serious health effects.
301 to 500	Hazardous	Health warnings of emergency conditions. The entire population is more likely to be affected.

Source: United States Environmental Protection Agency

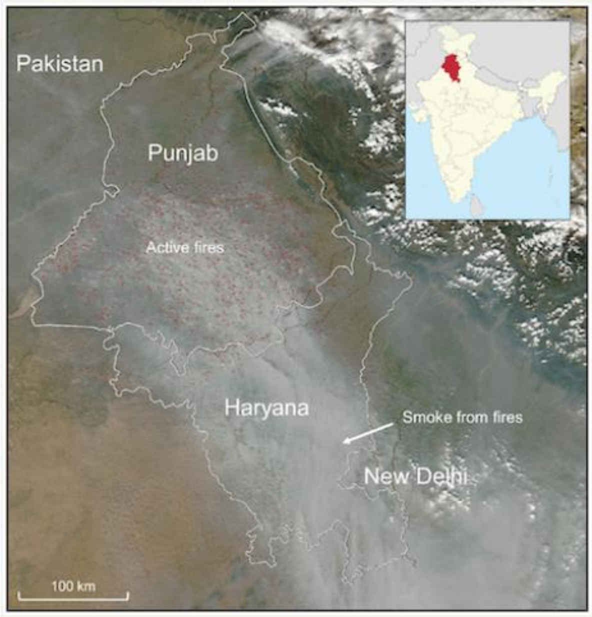
Case study 1- the link between crop burning and respiratory illnesses by IFPRI

Introduction: The International Food Policy and Research Institute in 2019 aimed to find the correlation between crop residue burning and its effects on human health, along with its estimated health and economic costs. As a part of the study the Institute analyzed the health data from more than 250,000 people belonging to different age groups in India. NASA satellite data was then used to monitor the fire activity in the country to estimate the health impact of living in areas with intense crop burning. It was found that air pollution arising from crop residue burning in Northern India, mainly Punjab, Haryana and Delhi, is causing severe health hazards to the residents. The findings of the study are enumerated below:

Smog from the crop residue burning:

Rice straw burning is mostly followed in the months of October to December, which is also the onset of winter in the Indian subcontinent. The smoke from the residue burning mixes with the dense fog in Northern India to produce smog, which creates a thick blanket of haze in the neighboring states. The NASA satellite image showing the fires and smog is shown alongside. The smoke can be seen in Punjab, Haryana, Delhi and some parts of Pakistan and Nepal. The study found that the levels of airborne particulate matter in Delhi spiked to 20 times the safe threshold proposed by the World Health Organization (WHO). Smoke from burning of crop residue in northwest India has been estimated to contribute up to 78 per cent of the enhancement in small particulate matter in Delhi on certain days.

Figure 72: NASA Satellite Image Showing Fires Caused by Crop Residue Burning



Source: NASA Satellite Image (IFPRI Report)

Health effects of crop residue burning:

The study found that the frequency of hospital visits for Acute Respiratory Infections (ARI) symptoms concurred the number of fires observed by the satellite image, i.e., as crop residue burning increased, the respiratory heath of residents worsened. It was found that in districts where crop residue burning was intense, residents, especially children under 5, were three times more likely to visit the hospital for symptoms of ARI. Similar results were found in the neighboring states of the burning sites.

Economic effects:

The study found that crop residue burning is the leading risk factor of ARI in India, and economic losses associated with its health effects are estimated at $35 billion per year. When combined with firecracker burning during the same months (October/November), the economic losses are nearly $152 billion over five years or 1.7 per cent of India's GDP.

Case study 2- Socio Economic impacts of smog in India and Pakistan

Introduction: The Sustainable Development Policy Institute (SDPI) has conducted a study to analyze the effects of smog in India and Pakistan using satellite images for the years 2017 and 2018. In Pakistan most of the rice cultivation takes places in Punjab and same goes for Indian Punjab due to similar climatic and geographic conditions. In both countries the rice straw is burnt after the harvesting season in October and November, which affects the air quality in the region. Seasonal meteorological conditions cause the smoke arising from crop residue burning to cover the whole Indo-Gangetic Plain and the residual smoke stays in the air for as long as three weeks. The figures below show the large amounts of smog (smoke mixed with fog in the winter season) engulfing India, Pakistan and some areas of Nepal. Figure 75 shows how the smog affects absorption and reflection of light by atmosphere. The darker color of the aerosols depicts larger concentrations of particulate matter in the air.

Figure 73: Aerosol Optical Depth Caused by Same Smog

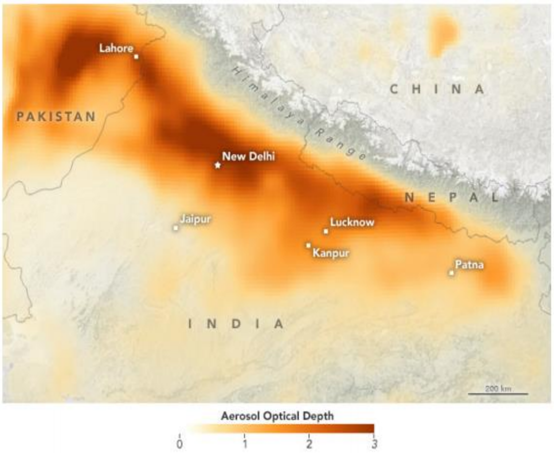
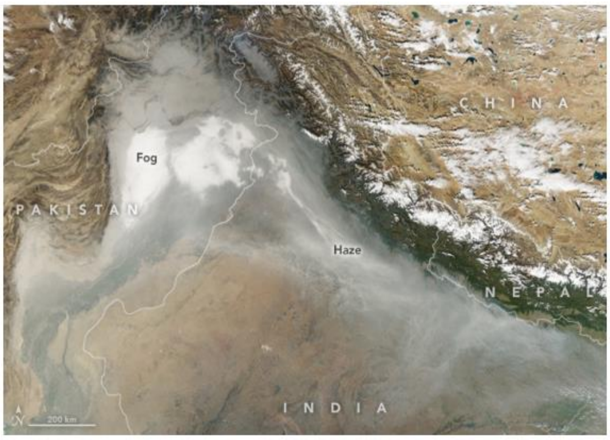


Figure 74: NASA Satellite Image Showing Smog (2017)



Source: NASA (2017)

Particulate Matter emissions: The table below shows the air quality in few areas in India and Pakistan a day after the satellite images were taken (8 November, 2017). The numbers show that the particulate matter is exceeding safe limits by more than 10 times. The safer limits of the permissible range of PM 2.5 and PM 10 is 0-60 µg/m3 and 0-100 µg/m3 respectively. Similar conditions were observed in October 2018 in both countries. With an increase in paddy production in both countries the quantum of residue burnt each year is also estimated to increase.

Table 71: Particulate Matter in India and Pakistan (November 2017)

Area	PM 2.5	PM 10
Pusa	521	537
Lodhi road	581	601
Mathura road	626	555
Ayanagar	531	589
Delhi University	609	669
Noida	575	600
Airport	541	585
Pitampura	570	624
Gurugram	536	583
Lahore	1,077	NA

Socio economic impacts of smog:

Smog is known to cause acute respiratory illnesses, cardiac issues, high blood pressure and eye irritations, with children being most vulnerable to its effects. Smog also causes asthma and tightening of throat, with some studies also suggesting cancer in women in the age group of 30-40 years. As per the study, almost 1000 new patients were treated for respiratory issues in nine public hospitals everyday due to smog in Lahore alone. Apart from the study, WHO estimates that as many as 60,000 people died in Pakistan in the year 2015 due to fine particulate matter. According to Lancet Commission air pollution causes 300,000 pre-mature deaths annually in Pakistan and 2.5 million deaths in India.

The biggest effect of smog is on the visibility on roads and highways next to the farms. On 5 November, 2017 a total of 10 people were killed and 25 injured due to visibility issues caused by smog in Lahore. On 9 November 8 more people were killed in Punjab in another road accident caused by low visibility. At the same time, the Air Quality Index in Delhi crossed values of 450, forcing the capital to declare a "public health emergency". The smog that had collected over days on the national highways caused a blanket of smoke that resulted in serial accidents. A total of 24 vehicles were piled up on the highway causing damage to vehicles and injuring several passengers.

Conclusion:

The above case studies focus on the effects of air pollution caused by crop residue burning in India and Pakistan. However, due to similar geographic conditions, harvesting patterns and seasonal meteorological conditions across the Indo-Gangetic Plain, similar effects can be assumed, with slight variation in seriousness, in all the other SAARC Member States following similar cropping patterns. The environmental effects of air pollution caused by crop residue burning in SAARC Member States is depicted in the sections below:

6.1.1 Afghanistan

Biomass combustion has several negative effects on the climate of Afghanistan.

Most often in the cold winter months, for several weeks in a row, the city gets blanketed by a toxic haze of particulate matter, small and often invisible particles of dust and soot.

Under normal circumstances, warm air close to the ground gradually rises, carrying pollutants with it and dispersing them. However, when cold air remains close to the ground, due to thermal inversion the pollution accumulates at the ground level.

6.1.2 Bangladesh

Severe environmental pollution caused due to biomass burning is one of the main causes of climatic changes, which is threatening human health and the economic growth of Bangladesh.

Due to the impact of air pollution, visibility reduces because of formation of smog, especially during the winter months. There is a rapid increase in the temperature and extreme climatic variations.

6.1.3 Bhutan

Bhutan is known as one of the countries with the cleanest air, but recent reports suggest that the country's air may not be as clean as it is thought to be. Due to increase in air pollution due to crop residue burning there have been several environmental issues in Bhutan.

An increase in black carbon concentration has been observed in recent times. Black carbon is fine particles in smoke emitted by burning of crop residues. It is not only black carbon emitted from within Bhutan, but also the sooty black material emitted from neighboring countries, which enters the country's atmosphere.

Black carbon absorbs the sunlight and reduces agricultural productivity. Its presence in the air also affects visibility, harms ecosystems and exacerbates global warming. It is one of the most significant contributors to climate change.

6.1.4 India

The main adverse effects of crop residue burning in India include the emission of greenhouse gases (GHGs) that contribute to the global warming, increased levels of particulate matter (PM) and smog that cause health hazards, loss of biodiversity of agricultural lands, and the deterioration of soil fertility.

Crop residue burning significantly increases the quantity of air pollutants such as CO_2, CO, NH_3, NOx, SOx, Non-methane hydrocarbon (NMHC), volatile organic compounds (VOCs), and semi-volatile organic compounds (SVOCs). This basically accounts for the loss of organic carbon, nitrogen, and other nutrients, which would otherwise have retained in soil.

The PM emitted from burning of crop residues in Delhi is 17 times that from all other sources such as vehicle emissions, garbage burning and industries. Crop burning increases the PM in the atmosphere and contributes significantly to climate change. The air pollution in Delhi has reached "Hazardous" (500+) levels in the months from October-December due to smog from stubble burning. Each year this smog causes fatal accidents in States of Punjab, Haryana, Uttar Pradesh and Delhi.

6.1.5 Maldives

In general, the air quality of Maldives is good. However, trans-boundary air pollution has become rampant. Most of the pollutants are primarily composed of black carbon and soot that come from the burning of biomass and fossil fuels. There is a strong heating effect of these pollutants.

This affects not only the air temperature, but also destroys millions of tons of coral reefs annually and causes human health concerns. If global warming continues at its current pace, it is expected that most of Maldives will be underwater before 2050.

6.1.6 Nepal

The lack of a stringent pollution regulation and management systems and large population growth have left a deep imprint on the environment in Nepal. Air quality in both urban and rural areas is deteriorating in the country greatly due to biomass burning, with Kathmandu in particular being at very high levels of risk. The bowl like topography of the Kathmandu valley restricts air movement, thereby accumulating high levels of dangerous pollutants. Black carbon is the main cause of air pollution in Nepal.

Black carbon and particulate matter fall on snow and darkens the surface, in the process reducing reflectivity and causing the surface to absorb more heat. Most of the black carbon falling on the Himalayas and the South of the Tibetan plateau comes from the plains of India, while that of the Eastern and Northern sections of the plateau comes mainly from China.

It is also responsible for a large part, around 30% of glacial retreat in the region. It absorbs lots of solar energy. It settles on glaciers and snow, and its dark color causes the snow and ice to absorb more of the sun's radiation. It also warms up the air, changing rainfall patterns.

6.1.7 Pakistan

In Pakistan, the melting of glaciers can be attributed mainly to the rising temperatures. One of the main causes for this temperature rise is crop residue burning, which is undertaken on a large scale. The wind-blown pollutants settle onto glaciers, darkening them and reducing their ability to reflect away sunlight, which leads to a faster rate of melting.

6.1.8 Sri Lanka

In Sri Lanka mainly due to residue burning, there has been a projected rise of the mean annual temperature by about 3.7°C on an average from 1990 to 2010. Other impacts are:

1. There are extreme climatic variations
2. Rise in the sea level due to greenhouse gases is leading to rampant floods and cyclones
3. Coral reefs are getting severely damaged

4. There is an alarming rate of biodiversity loss and degradation of the ecosystem

6.2 Study of Health Effects of Crop Residue Burning in each Member State

Air pollution exposure is the second most important risk factor for ill health among South Asian countries. Crop residue combustion is one of the major causes of air pollution especially in the SAARC countries. Large amounts of black carbon and particulate matter are emitted into the atmosphere, which leads to very serious health disorders. Countries like Bangladesh, India, and Pakistan, which have larger populations, have more people exposed to toxic emissions, and therefore, many people are being affected by chronic diseases.

6.2.1 Afghanistan

Air quality in Afghanistan has been deteriorating rapidly over the years. One of the major causes happens to be pollution due to crop residue burning. The Government is still in the process of adopting proper air quality management standards. The most common health effects experienced by the citizens are:

1. Difficulties in breathing
2. Skin problems
3. Irritations to their eyes, nose, and throat

6.2.2 Bangladesh

In Bangladesh, air pollution due to agriculture residue burning is posing a severe risk to public health. The presence of fine particles in the air is linked to sickness and hospitalization as they cause a wide range of health effects, including:

1. Respiratory symptoms (coughing, wheezing, reduced lung function)
2. Chronic obstructive pulmonary disease, lung cancer, heart attacks, arteriosclerosis, strokes, high blood pressure, and asthma
3. PM10 and PM2.5 are also linked to premature death from cardiovascular and respiratory diseases and lung cancer

6.2.3 Bhutan

Air pollution due to crop residue burning is becoming a serious concern in Bhutan. Fine particles which are emitted from residue burning penetrates deep into the respiratory tract subsequently increase mortality from respiratory infections, lung cancer and cardiovascular disease. Short-term symptoms resulting from exposure to air pollution include:

1. Itchy eyes, nose, and throat,
2. Wheezing, coughing,
3. Shortness of breath, chest pain, headaches, nausea,
4. Upper respiratory infections (bronchitis and pneumonia).
5. It also exacerbates asthma and emphysema.
6. Long-term effects include lung cancer, cardiovascular disease, chronic respiratory illness, and developing allergies.

6.2.4 India

In India, exposure to air pollution, both household and ambient, is associated with a broad range of acute and chronic health effects from minor physiologic disturbances to death from respiratory and cardiovascular diseases. Short-term exposure to ambient particulate and gaseous pollutants has been linked to:

1. Higher rates of hospital admissions for cardiovascular and respiratory illnesses
2. Exacerbation of pre-existing respiratory illnesses
3. Death through ischemic heart disease or stroke
4. Longer-term exposure to PM2.5 has been associated with ALRI in children, developmental disorders, cardiovascular mortality, decreased lung function, COPD, diabetes, and lung cancers

6.2.5 Nepal

Nepal, especially Kathmandu, in the current situation, is observing rapid urbanization and various infrastructure development projects. As a result, these sorts of human activities have been responsible for increasing air pollution in an enormous rate inside Kathmandu Valley.

Chronic exposure of deteriorated air increases the chance of Non-communicable Disease (NCD) like lung disease, heart disease, and cancers.

Short-term exposures also invite respiratory diseases and allergy

6.2.6 Pakistan

In Pakistan, the most important factor that affects human health is air pollution due to residue burning. Some of the adverse health effects include:

1. Acute Respiratory Infection (ARI) and other lung diseases are related directly to pollution in the air
2. Other respiratory diseases such as asthma and bronchitis
3. Skin allergies
4. Eye irritation

6.2.7 Maldives

The major health problems include respiratory infections and breathing issues

6.2.8 Sri Lanka

Air pollution due to agriculture residue burning is a major public health concern in a developing country like Sri Lanka. Major health problems include:

1. Respiratory diseases like asthma, bronchitis etc.
2. Skin allergies
3. Throat infections

7 Barriers and Challenges

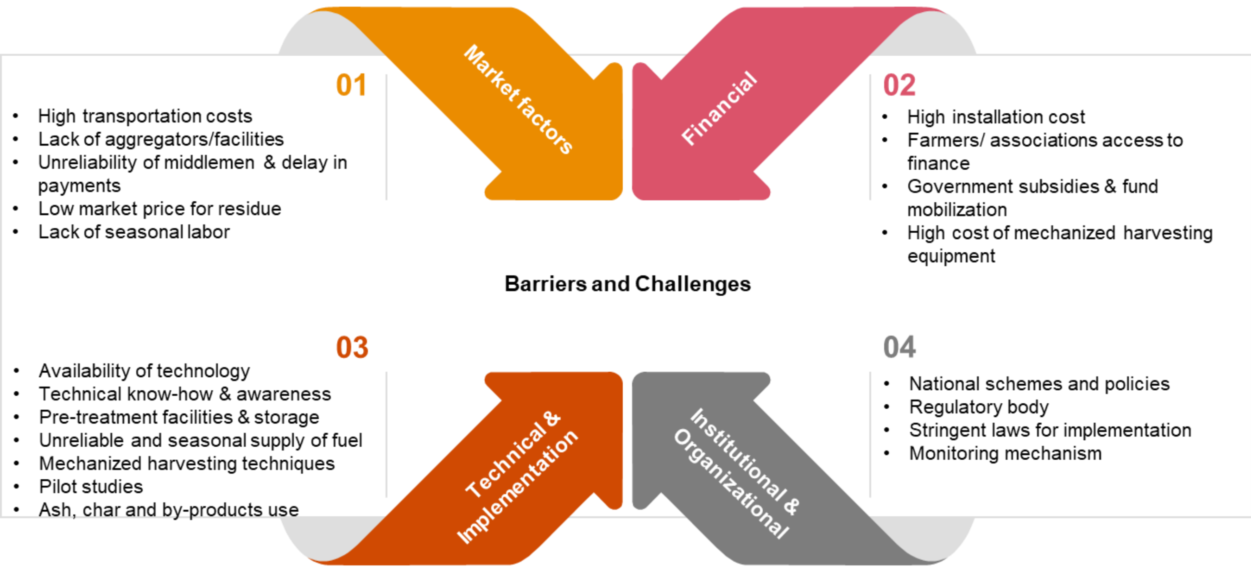
7.1 Classification of Barriers and Challenges

In general, the deployment of biomass generated energy programs in the SAARC countries has been slow. Although there is an established high volume of crop residue available in these countries, the adoption and implementation of biomass derived energy projects face several issues. This section enlists the specific barriers and challenges in the development and deployment of agricultural waste-based energy generation projects.

The key challenges have been divided into four broad categories:

1. Market factors
2. Financial Challenges
3. Technical and Implementation Challenges
4. Institutional and Organizational Challenges

Figure 75: Barriers and Challenges



7.1.1 Market Factors

Fuel supply risk: There is a very high fuel supply risk associated with availability of agricultural residue all year round to ensure the technical and financial viability of projects. The physical availability of crop residue is a major risk as it is directly linked with the crop production, that is further dependent on various factors like rainfall, agricultural practices, harvesting effectiveness, irrigation, and productivity.

Secondly, this fuel must be contracted by the suppliers to ensure continuity and assurance of residue. The inability of developers to lock-up enough biomass from various sources serves as a hindrance to project implementation and sustainability. The fuel-supply agreements and supply chain are major operational issues faced by most developers.

Transportation cost: Farmers regard transportation cost and reliability as the main barriers to supply crop residue to the power plants. In many cases the responsibility of supplying the fuel to the power plants lies with the farmers or aggregators. The key logistical issue associated with residue mobilization is the unavailable, unreliable, costly, and ageing transportation fleet. Bad conditions of rural roads add to the logistical issues. In most cases the price realized by sale of residue does not cover the transportation cost of fuel supply and is therefore not preferred by small farmers.

Supply chain and lack of aggregators: Farmers also consider the lack of aggregating facilities/ terminals and well-established supply chain as a common barrier in supply of residue for processing. In the absence of aggregating bodies located at the periphery of villages or few kms, the farmers are forced to supply the residue to the plants themselves. Farmers generally do not have the necessary transportation means required to mobilize Tons of residue individually.

Low market price for residue: Farmers complain of low-price realization of their residue during low-demand and good-harvest seasons. Farmers are of the opinion that the Government should fix a fair residue price based on the season and type, along with terminals setup at village or taluka level collection of residues.

Unreliability of middleman and delay in payments: Another key issue is the involvement of middleman or aggregator in the residue procurement process from farmers. The middlemen are also suspected of forming cartels in many villages and offer lower prices for the residue, often after delay of many months. In such cases, the farmers are willing to supply residue directly to energy producers without the involvement of these middlemen, but lack the suitable transportation means to do so.

Lack of seasonal labor: Farmers also face challenges in obtaining cheap labor during peak harvesting seasons. During such time the window for efficient harvesting is very less (2-3) and the hourly hire rates of local labor is very high due to increase in demand. The lack of such labor drives them to burn the residue instead of paying high prices for labor or rentals towards mechanized harvesting equipment

7.1.2 Financial Challenges

Limited access to funds: Biomass-based energy projects are generally implemented on smaller scales in the SAARC nations by local investors. The farmers, co-operatives and developers face a major hurdle in securing the necessary funds due to lack of credit scores and their inability to repay them due to fluctuations in their agricultural income. Additionally, there is a lack of established lenders for projects in smaller villages in the SAARC nations. Furthermore, private sector participation is minimal for agricultural lending and developers are forced to rely on limited government funds and grants.

High installation cost: The installation of a mini-power generation at a village level is about USD 21,000-30,000, of which, some may be provided through government subsidies. The remaining cost of installation must be borne by the farmers, or in some cases farmer's associations and co-operatives. Farmers in SAARC nations typically have small land holdings and find it difficult to secure the required capital investment. The developers face difficulties in raising debt from banks due to perceived high risks by Financial Institutions because of the limited number of visibly successful demonstrations.

Incentives and subsidies: To deter stubble burning, it is imperative to provide farmers enough financial support and incentives for implementing in-situ and ex-situ residue management techniques. The in-situ management techniques include use of combine harvesters, Super SMS, and Happy Seeders. The Government of India offers 50%-80% subsidy on purchase of mechanized harvesting machines. The funds are mobilized through different ministries like MOEF&CC, MoRD and banks like NABARD to support State Governments through various on-going schemes. The states can also provide financial assistance to farmers under the Rashtriya Krishi Vikas Yojana to fund such mechanized harvesters. However, despite the many incentives and subsidies provided by the government to access equipment, the farmers still must pay USD 7,000-15,000 per machine as capital investment. Most farmers do not have access to such finance.

Government grants: To implement ex-situ treatment plan like setup of decentralized power generation plant, palletization and briquetting plant or biogas plants require high capital investment. Some governments provide financial assistance via Viability Gap Funding, in which the government invests up to 25% of the capital cost through various state grants. Such grants are disbursed on priority, feasibility and availability and may not be accessible to all developers.

7.1.3 Technical and Implementation Challenges

Lack of technology: The technologies for agricultural waste-based power generation have not been fully standardized, packaged, documented, and validated for commercial usage in the SAARC countries. There are only a handful of projects implemented in India and Pakistan on small scale, while the other countries lack the technical capacity to implement them.

Scale up of technology: The biomass power generation technology, although mature and successfully implemented on smaller scale, faces significant barriers in deployment on a large scale, owing massively to the difficulty in sourcing a reliable and affordable supply of year-round biomass.

Technical know-how and awareness: The information on viable technological configurations and projects is limited and as such the knowledge dissemination remains unsuccessful to reach stakeholders, like farmers, co-operations, investors, and project developers. In most villages, the farmers are unaware of any technological usage of their agricultural waste and the residue remains unutilized.

Pre-treatment and storage of fuel: In most cases the residue needs to be pretreated before use in gasifiers or ethanol plants to achieve the desired efficiency as per the plant's design parameters. These pretreatment procedures include baling, shredding, preparing smaller particles, pelletizing, or briquetting. The smaller and compact residue sizes also make it possible to reduce the transportation costs. Since most of the residue is procured from rural areas, there is a lack of such equipment to prepare the desired product. Additionally, the large residue sizes require extra storage space at the power plant's premises, thus, making them undesirable for purchase.

Lack of suitable mechanized harvesting techniques: Many farmers in the sub-continent have adopted mechanized harvesting equipment in the past five years. The combine harvester, which is the most used harvesting technology, leaves behind unevenly spread crop residue and standing short stubble in the fields. Since farmers focus more on quickly harvesting the current crop and not budgeting the time required for sowing the next crop, they resort to stubble burning for a quick solution. Technologies like the Super SMS takes care of this problem of incomplete residue cutting, but it comes at an additional cost of USD 1,700-2000 per piece. Farmers do not perceive this as a cost-effective solution and prefer the burning of stubble instead.

Ash and char utilization: Gasification of crop residue to produce electricity produces some by-products like tar, ash, and char. The tar does not value add to any processes or people and must be cleaned off to maintain smooth operations of the equipment. The ash and char on the other hand find applications in brick & cement making industries and as a source of fuel and soil enhancer respectively. However, lack of suitable buyers for both proves as a deterrent for developers and operators. The ash and char are usually dumped in nearby wastelands which add to the environmental hazards.

7.1.4 Institutional and Organizational Challenges

Institutional support and policies:

A review of each country's laws and policies regarding crop residue management is shown below to assess their institutional arrangements for application of suitable agricultural biomass management techniques.

Table 72: Regulatory Review of SAARC Member States

Country	Agricultural Regulatory Body	National schemes & policies for crop residue management
Afghanistan	√	X
Bangladesh	√	X
Bhutan	√	X
India	√	√
Maldives	√	X
Nepal	√	X
Pakistan	√	X
Sri Lanka	√	X

While all the SAARC countries have an apex body for formulation and administration of rules, regulations and laws pertaining to agriculture and its practices in the country, only India has formulated a National Policy for Management of Crop Residue (NPMCR) in the year 2014. The main objectives of the policy are to:

1. Promote the technologies for optimum utilization and in-situ management of crop residue and diversify uses of crop residue in industrial applications like power generation, bio-fuel production, packaging material etc.
2. Develop and promote appropriate crop machinery in farming practices. Provide discounts and incentives for purchase of mechanized sowing machinery such as the happy seeder, turbo seeder, shredder, and baling machines.
3. Use satellite-based remote sensing technologies to monitor crop residue management with the National Remote Sensing Agency (NRSA) and Central Pollution Control Board (CPCB).
4. Provide financial support through multidisciplinary approach and fund mobilization in various ministries for innovative ideas and project proposals to accomplish above.

In 2017, the Government of India has also mandated its largest thermal utility, NTPC, to blend 10% crop residue with coal in a bid to reduce agricultural residue burning. Under the program, NTPC will buy crop residue from farmers and use it to make biomass pellets to co-fire with coal at all its plants across India.

The Government of India also has set an ambitious target of renewable energy capacity addition to 175 GW by the year 2022, of which 10 GW is to be contributed by biomass power. Since its announcement in December 2016, the capacity addition under biomass derived power has increased from 7.8 GW to 9.2 GW in July 2019. The Government has provided the required thrust and support in the form of increased budget to The Ministry of New and Renewable Energy (MNRE) (nodal agency for matters relating to new and renewable energy) and cuts on import duties for biogas plant components.

While India is in the forefront of such policy and regulatory interventions the other SAARC countries lack any such institutional support for crop residue management by their apex bodies.

Furthermore, there is a lack of stringent monitoring mechanisms in all the SAARC countries, including India, to monitor the implementation of any intervention undertaken by State governments/ provinces for crop residue burning. A monitoring cell at State and National level is absent for examining the implementation of measures to curb the practice.

8 Conclusion and Recommendations

It is estimated that over 110 million Tons of surplus agricultural residue is burnt every year in the SAARC nations, of which, 75-80% is contributed by India alone. Farmers prefer residue burning on account of a very short window of 2-3 weeks between subsequent cropping seasons and requires no cost. This leaves them with inadequate time to prepare the next crop or use time-consuming methods for removal of the farm residue. Burning of crop residue leads to release of soot and smoke causing health issues, low visibility and accidents, emission of greenhouse gases (GHGs), loss of plant and soil nutrients. Globally, agriculture, forestry and land use sector contribute to 24% of the GHG emissions, of which 17-18% comes from South Asian countries. Crop residue burning is a major contributor of this agricultural GHG emissions. To meet the target of the Paris Agreement, 2015 which the SAARC Member States are a part of alternate uses of crop residue must be identified. The crop residue can be utilized to generate bioenergy in various forms to substantially reduce GHG emissions, displace fossil fuels and provide a source of renewable energy in the rural parts of these countries which still lack access to electricity.

Crop residue finds application in production of decentralized electricity through use of different gasification technologies, biofuels that can be used for transportation, space heating and cooking applications on domestic, commercial, and industrial scale. The end use of the crop residue is determined based on the type of residue, availability, volume, energy content and use of its by-products.

It is observed that most crop residue burning in the SAARC Member States is practiced for rice and wheat stubbles. After the harvesting of these crops, the residue left behind in the fields, like straws, stalks and leaves are burnt each year to quickly prepare the field for sowing of the next crop. The burning of these two crops' residues are the major contributors for excessive particulate matter emissions and air pollution along with smog in the winter. Hence only these field-based residues have been considered for estimating the energy generation potential in the SAARC Member States.

The Gross residue, Surplus residue and power generation potential using only rice and wheat straws and stalks for each Member State is shown below. It is recommended that in smaller countries with lower power generation potential, the biomass plants be set up in a central location, whereas in larger countries a regional level implementation of energy projects is recommended for easy aggregation of residue.

Table 73: Total Power Production Potential of SAARC Member States Using Only Farm-Based Residues

Member State	Residue used	Total wheat and rice production (Million Tons)	Gross Residue Production (Million Tons)	Surplus Residue Production (Million Tons)	Total Power Generation Potential (MW)
Afghanistan	Wheat straws	4.2	6.4	1.4	58
Bangladesh	Rice and Wheat straws	38.1	57.2	15.6	1,100
India	Rice and Wheat straws	212.6	319	80.3	5,395
Nepal	Rice and Wheat straws	7.7	11.6	3	140
Pakistan	Rice and Wheat straws	36.3	54.4	13	834
Sri Lanka	Rice straws	2.4	3.5	1	71
Total		**301**	**452**	**114**	**7,598**

8.1 Country-wise Implementation Plan

The above table gives a country-wide potential for power generation using agricultural residues. However, in most countries with rice-wheat pattern of cultivation the power plant size can be optimized to operate on rice stalks and straws after the end of the Kharif season and on wheat stalks and straws at the end of the Rabi season. This will help in reducing the power plant capacities by 30-40% (depending on residue production potentials), with a resultant reduction in capital costs, land requirement for plant installation and fuel storage areas. Thus, the current implementation plan focuses on residue derived from rice-wheat production only, for they are most prone to crop residue burning each year.

Different models for implementation for each country can be developed based on the plant capacity and end-use of electricity generated. For smaller plant sizes, the BOM (Build, Own and Maintain) or the BM (Build and Maintain) model can be adopted, wherein a local entrepreneur in the region can invest the required capital and the plant ownership can be transferred to them after the end of predetermined period. This model may not be suitable for plants of higher capacities, where the capital cost cannot be arranged by local players. In such cases it is recommended to go for a BOOM (Build, Own, Operate and Maintain) model where the capital cost is invested completely by a private player or the government(s).

Assumptions made for preparation of commercial model and implementation plan:

The capital cost of project implementation may vary between 10-15% for different SAARC Member States, as well as the interest rates on loans. The revenue is also largely affected by the cost of biomass in the Member States, which also show a variation of 10-30% in different countries and regions. The commercial model has been constructed keeping similar assumptions in mind.

8.1.1 Afghanistan

Wheat production in the country account for over 80% of the total crops cultivated annually. Taking into consideration the high heating values (17-18 MJ/kg) of their residue, it is suggested to install wheat residue-based gasifier plants in areas with high production and easy aggregation. ~70% of wheat is cultivated in concentrated locations in the North and North-Western regions of Balkh, Kunduz, Takhar, Faryab, Herat. The region-wise implementation plan is provided below. The power generation potential has been derived for a residue collection efficiency of 50%.

Table 74: Implementation Plan for Afghanistan

Particular	Details			
Total Surplus Residue Potential for energy generation		1.4 million MT		
Residue Collection Efficiency		50%		
Total Power Generation Potential		58 MW		
Region wise implementation				
Location	**North**	**East**	**West**	**South**
Province name	Balkh and Kunduz Provinces	Ghazni Province	Herat Province	Helmand Province
Plant capacity	32 MW	12 MW	7 MW	7 MW
Annual requirement	Wheat straw: 388 thousand Tons	Wheat straw: 141 thousand Tons	Wheat straw: 85 thousand Tons	Wheat straw: 92 thousand Tons
Capital investment	27 million USD	141 million USD	6 million USD	6 million USD

8.1.2 Bangladesh

Of the total crop production of Bangladesh, rice and wheat contribute ~47% (38 million MT) and are most prone to in-situ burning after their harvest. Their collective surplus residue if utilized towards energy generation can produce 1100 MW of power. However, given the complementary nature of their production and harvesting, it is recommended to implement smaller size biomass gasifier plants that will run alternatively on rice and wheat residues. This will also ensure reduced capital costs, land requirement and storage space for the residue. Accordingly, the plant capacities have been optimized and will operate on a residue collection efficiency of 75%. With an increase in the collection efficiency additional plants may be installed in the future to meet the rise in supply.

Table 75: Implementation Plan for Bangladesh

Particular	Details			
Total Surplus Residue Potential for energy generation	15.6 million MT			
Residue Collection Efficiency	75%			
Total Power Generation Potential	1100 MW			
Region wise implementation				
Location	**North**	**East**	**West**	**South**
Division name	Rangpur, Sylhet and Mymemshing	Dhaka and Chittagong	Rajshahi and Khulna	Barishal
Plant capacity	359 MW	269 MW	317 MW	68 MW
Annual requirement	Rice straw: 3,774 thousand Tons Wheat straw: 416 thousand Tons	Rice straw: 2824 thousand Tons Wheat straw: 179 thousand Tons	Rice straw: 3,334 thousand Tons Wheat straw: 473 thousand Tons	Rice straw: 717 thousand Tons Wheat straw: 5 thousand Tons
Capital investment	304 million USD	228 million USD	269 million USD	58 million USD

8.1.3 Bhutan

The country produces rice and maize in lower altitudes along with seasonal vegetables. As such the energy potential of the country is very low due to non-availability of surplus crop residue. The country has been excluded from any energy generation analysis.

8.1.4 India

In India, rice and wheat contribute ~30% of the total food crop production. It is recommended to divide the total energy potential of the country in North, East, West and South zones based on the type of crop cultivated and potential for surplus residue.

Considering only the field-based residues from rice and wheat that are responsible for crop residue burning (like stalks and straws) the following implementation plan has been recommended. Their collective surplus residue if utilized towards energy generation can produce 5,395 MW of power. However, given the complementary nature of their production and harvesting, it is recommended to implement smaller size biomass gasifier plants that will run alternatively on rice and wheat residues. This will also ensure reduced capital costs, land requirement and storage space for the residue. Accordingly, the plant capacities have been optimized and will operate on a residue collection efficiency of 75%. With an increase in the collection efficiency additional plants may be installed in the future to meet the rise in supply.

Table 76: Implementation Plan for India

Particular	Details			
Total Surplus Residue Potential for energy generation	80.3 million MT			
Residue Collection Efficiency	75%			
Total Power Generation Potential	5,395 MW			
Region wise implementation				
Location	**North**	**East**	**West**	**South**
State name	Uttar Pradesh, Haryana and Punjab	West Bengal and Bihar	Maharashtra and Madhya Pradesh	Tamil Nadu and Karnataka
Plant capacity	1,207 MW	1,252 MW	664 MW	711 MW
Annual requirement	Rice straw: 9959 thousand Tons Wheat straw: 14805 thousand Tons	Rice straw: 13160 thousand Tons Wheat straw: 1727 thousand Tons	Rice straw: 4979 thousand Tons Wheat straw: 8143 thousand Tons	Rice straw: 7469 thousand Tons Wheat straw: 113 thousand Tons
Capital investment	1,023 million USD	1,060 million USD	562 million USD	602 million USD

8.1.5 Maldives

The country produces only coconut on its islands and 90% of the food crops are imported for sustenance. Due to this the energy generation potential of the country is very low due to non-availability of surplus crop residue. The country has been excluded from any energy generation analysis.

8.1.6 Nepal

The total energy potential in Nepal is considered using cereal crops- rice and wheat. The implementation plan has been recommended keeping in the mind the areas with highest production and easy aggregation. The production from the Mid-Western and Far-Western divisions have been clubbed into one area.

The collective surplus residue of rice and wheat straws and stalks if utilized towards energy generation can produce 140 MW of power. However, given the complementary nature of their production and harvesting, it is recommended to implement smaller size biomass gasifier plants that will run alternatively on rice and wheat residues. This will also ensure reduced capital costs, land requirement and storage space for the residue. Accordingly, the plant capacities have been optimized and will operate on a residue collection efficiency of 50% given the difficulties in aggregation due to the hilly terrain of the country. With an increase in the collection efficiency additional plants may be installed in the future to meet the rise in supply.

Table 77: Implementation Plan for Nepal

Particular	Details
Total Surplus Residue Potential for energy generation	3 million MT
Residue Collection Efficiency	50%
Total Power Generation Potential	140 MW

Region wise implementation				
Location	**Eastern Region**	**Central Region**	**Western Region**	**Far Western Region**
Division name	Jhapa and Morang	Dhanusha and Sarlahi	Nawalparasa	Kailali and Kanchanpur
Plant capacity	29 MW	29 MW	24 MW	27 MW
Annual requirement	Rice straw: 309 thousand Tons Wheat straw: 53 thousand Tons	Rice straw: 310 thousand Tons Wheat straw: 125 thousand Tons	Rice straw: 249 thousand Tons Wheat straw: 66 thousand Tons	Rice straw: 283 thousand Tons Wheat straw: 127 thousand Tons
Capital investment	25 million USD	25 million USD	20 million USD	23 million USD

8.1.7 Pakistan

In Pakistan, rice and wheat contribute ~30% of the total food crop production. Considering only the field-based residues from rice and wheat that are responsible for crop residue burning (like stalks and straws) the following implementation plan has been recommended. Their collective surplus residue if utilized towards energy generation can produce 834 MW of power. However, given the complementary nature of their production and harvesting, it is recommended to implement smaller size biomass gasifier plants that will run alternatively on rice and wheat residues. This will also ensure reduced capital costs, land requirement and storage space for the residue. Accordingly, the plant capacities have been optimized and will operate on a residue collection efficiency of 75%. With an increase in the collection efficiency additional plants may be installed in the future to meet the rise in supply.

Table 78: Implementation Plan for Pakistan

Particular	Details			
Total Surplus Residue Potential for energy generation	13 million MT			
Residue Collection Efficiency	75%			
Total Power Generation Potential	834 MW			
Region wise implementation				
Location	**North**	**East**	**West**	**South**
Province name	Khyber Pakhtunkhwa Province	Punjab Province	Baluchistan Province	Sindh Province
Plant capacity	131 MW	155 MW	131 MW	155 MW
Annual requirement	Wheat straw: 1608 thousand Tons	Rice straw: 1625 thousand Tons Wheat straw: 1608 thousand Tons	Wheat straw: 1608 thousand Tons	Rice straw: 1625 thousand Tons Wheat straw: 1608 thousand Tons
Capital investment	111 million USD	131 million USD	111 million USD	131 million USD

8.1.8 Sri Lanka

Rice production in the country account for over 90% of the total crops cultivated annually. Taking into consideration the high heating values (15-16 MJ/kg) of their residue, it is suggested to install rice residue-based gasifier plants in areas with high production and easy aggregation. The energy generation potential has been calculated for a residue collection efficiency of 75% on a conservative scale. With an increase in the collection efficiency additional plants may be installed in the future to meet the rise in supply.

Table 79: Implementation Plan for Sri Lanka

Particular	Details			
Total Surplus Residue Potential for energy generation	1 million MT			
Residue Collection Efficiency	75%			
Total Power Generation Potential	71 MW			
Region wise implementation				
Location	**North**	**East**	**West**	**South**
District name	Anuradhapura and Mannar	Mahaweli and Ampara	Kurunegala and Gampaha	Hambantota
Plant capacity	11 MW	38 MW	17 MW	6 MW
Annual requirement	Rice straw: 113 thousand Tons	Rice straw: 398 thousand Tons	Rice straw: 180 thousand Tons	Rice straw: 60 thousand Tons
Capital investment	9 million USD	32 million USD	15 million USD	5 million USD

8.2 Power Generation Potential Including Husk Residue

Section 8.1 of this report considers the energy generation potential of the SAARC Member States using only farm-based residues of wheat and rice harvesting that are most prone to burning, i.e., straws and stalks. However, there are also other residues generated from the harvesting and processing of rice and wheat crops, such as husks and shells. These residues are available in rice and wheat mills and are already being used for energy generation and allied purposes through established and regulated channels in these countries. If this husk is also considered for energy generation purposes the power generating potential of the Member States increases substantially. It is pertinent to note that different supply chains need to be established for procurement of farm-based residues and milling process derived residues. The transportation, price, and storage methods for both these types of residues will be distinct from one another. The table below illustrates the Gross residue, Surplus residue and power generation potential using all the residues of wheat and rice for each Member State.

Table 80: Total Power Production Potential of SAARC Member States Using All the Residues

Member State	Residue used	Total Wheat and Rice Production (million Tons)	Gross Residue Production (million Tons)	Surplus Residue Production (million Tons)	Total Power Generation Potential (MW)
Afghanistan	Wheat straws & husks	4.2	7.7	1.7	69
Bangladesh	Rice, Wheat straws & husks	38.1	65.3	17.8	1,253
India	Rice, Wheat straws & husks	212.6	371.4	93.2	6,249
Nepal	Rice, Wheat straws & husks	7.7	13.3	3.5	160
Pakistan	Rice, Wheat straws & husks	36.3	64.3	15.2	980

Member State	Residue used	Total Wheat and Rice Production (million Tons)	Gross Residue Production (million Tons)	Surplus Residue Production (million Tons)	Total Power Generation Potential (MW)
Sri Lanka	Rice straws & husks	2.4	4.0	1.1	81
Total		**301**	**526**	**133**	**8,792**

8.3 Implications of Mechanized Harvesting on the Energy Generation Potential

The different equipment and machinery used to increase the efficiency in harvesting and sowing have been discussed in Section 3.1.4. Machinery such as the happy seeder are being promoted for use by the governments of major countries to effectively manage the residues in the farms and curb crop residue burning. Currently the cost of the happy seeder is USD 2,500- 2,800. In India, the Ministry of Agriculture & Farmers' Welfare provides an 80% subsidy to farmer groups and 50% subsidy to individual farmers for purchase of the happy seeder. However, the cost of the happy seeder after subsidy is still high for farmers with small land holdings and only about 2-3% of farmers employ the machine to manage their farm residues. Given a possibility that the happy seeders become financially viable for farmers in the next few years the residue generation potential will reduce substantially. With wide-spread use of the happy seeder and subsequent reduction in residue generation, the energy generation programs may not remain economically viable. The current power generation potential derived for the SAARC Member States is made based on the utilization of happy seeder in these countries as on date.

8.4 Recommendations to Overcome Barriers in Deployment

As covered in previous sections, the key challenges for deployment of energy generation applications are divided into four broad categories:

1. Market factors
2. Financial challenges
3. Technical and Implementation Support
4. Institutional and Organizational challenges

A country-wise analysis of these issues reveals that they are common for most SAARC countries and solutions can be applicable to most Member States. This section provides recommendations and steps to overcome the identified challenges and barriers:

8.4.1 Market Factors

8.4.1.1 Aggregating Terminals

The biggest hurdle faced by farmers in supplying the crop residue is the lack of transportation facilities. It is recommended to set up regional level collection centers that are easily accessible by farmers using bullock carts, small tempos or in some cases, tractors. This will ensure maximum participation by farmers as they now do not have to travel large distances up to the plant location for sale of their product. These terminals shall also act as storage facilities to provide steady source of raw materials to the power plants.

To ensure financial viability of the project and reduce transportation losses it is recommended to establish collection centers after each 20 km in the identified districts/ provinces/ states with highest residue generation. By establishing smaller collection centers in easily accessible locations the cost of procuring large land parcels for residue storage at the plant location is greatly reduced.

8.4.1.2 Price Realization

It is recommended that the agricultural regulatory body aids in discovering a fixed price for different types of residues depending on the harvesting season and region. The prices can then be displayed on the national portal for farmers and developers to reduce instances of cheating by the aggregators or developers.

8.4.2 Financial

8.4.2.1 Government Financial Support for Equipment and Plant

The funds required for successful crop residue management should be effectively mobilized through different regional/ state/ provincial governments. Such funds can be provided to farmers or project developers through the various on-going schemes/ programs introduced to curb crop residue burning.

The government can provide central subsidies or grants for purchase of efficient and faster harvesting equipment and machineries (combine harvesters, super SMS, happy seeders, rotovators) to the farmers to facilitate in-situ management of crop residue and retaining the straw for mulching.

Furthermore, the government can also incentivize the establishment of energy generation projects aiming at utilization of crop residue by providing them fiscal benefits and grants. These can also include subsidies supporting R&D, low interest loans to projects, grants to rural households for setup of biogas plants. The government can also provide tax incentives to bioenergy projects, including reduced custom taxes for imported equipment and income tax holiday benefits.

The apex regulatory body can also design a centralized application process for farmers/ associations and project developers for availing such grants and subsidies, followed by a transparent process of transfer and monitoring of funds/support.

8.4.2.2 Access to Funds

Mainstream Financial Institutions are reluctant to provide loans to bioenergy projects due to their perceived high investment risks and non-guarantee of repayments. In India, most projects are being

financed by a handful of financial institutions, namely, Indian Renewable Energy Development Agency (IREDA), Industrial Development Bank of India (IDBI) and Industrial Credit and Investment Corporation of India (ICICI). It is recommended to increase the private sector participation in funding of viable and socially benefitting bioenergy projects. Other such sources of funds have been discussed below:

Loans/ Grants from multilateral agencies:

One of the most notable funding vehicles for gaining access to grants/ concessional loans for critical issues is through Multilateral Agencies. It is generally considered as a more non-political form of aid encouraging international cooperation. SAARC Member States could reach out to such agencies requesting support for implementation of energy generation programmes through funding of various initiatives covering pilot projects and setting up of necessary infrastructure.

1. Asian Development Bank (ADB) has set investments towards programmes for financing clean energy projects to help developing member countries provide reliable, adequate, and affordable energy for economic growth. Under ADB’s 2009 Energy Policy, the agency aims to introduce advanced technologies to increase energy efficiency by focusing on renewable energy and to improve access to energy for poor and remote regions.
2. The UK Department for International Development (DfID)- National Investment and Infrastructure Fund (NIIF) is fully attributed to climate change mitigation. The fund focuses on projects that help in

low carbon development and greenhouse gases emissions. The fund primarily invests in sectors like Renewable Energy, Clean Transportation, Water Treatment, and Waste Management.

3. The World Bank provides low-interest loans, zero to low-interest credits and grants to developing countries to support investments in areas of energy efficiency and implementation of energy generation programmes. World Bank also takes support from governments, other multilateral institutions, commercial banks, export credit agencies, and private sector investors for financing of such projects.
4. Asian Infrastructure Investment Bank is a multilateral development bank which focuses on sustainable infrastructure and other productive sectors in Asia. The bank, in collaboration with private investors, secure funding for renewable energy project development and reduce the carbon intensity of energy supply in the Asian region.

These agencies have set processes for evaluation of proposed projects which includes reviewing technical and financial feasibility of the project along with its adherence to the agency's overall strategy. After proper due-diligence, negotiations and approvals, the project gets a financial closure which is then monitored continuously by the agency for effective execution.

8.4.3 Technical & Implementation Support

8.4.3.1 Crop production and Infrastructure Assessment

The governments of each Member State can assist in the implementation of bioenergy projects by ensuring reliable information is available for study. The Nodal Agriculture Agency can conduct a detailed resource assessment for different crops and regions, along with their quantum of production and timeline of availability for each Member State. Furthermore, the electricity demand estimation of a certain region can be used to locate the end-users for the energy generated. This information can then be used by developers and researchers in estimating the scale and type of bioenergy program most suitable for each region and crop based on availability.

8.4.3.2 Awareness Campaigns

At the outset, most farmers are not aware of the crop residue management techniques and their benefits: social, economic, and environmental. They are even less educated about the technological interventions available to ensure efficient residue management. As a first step, the government or regulatory body should organize training campaigns for farmers to create awareness about the effects of crop residue burning, methods of residue conservation for better use and technologies available through ongoing programs and schemes.

These awareness campaigns could also provide a good platform for exchange of best practices among farmers and industry experts to promote residue usage. Along with awareness campaigns, skill development programmes can also be organized to train people across targeted regions with necessary expertise to operate machinery for harvesting/sowing, set-up and operation of biomass power plants and proper storage and transportation methods.

8.4.4 Institutional and Organizational

8.4.4.1 Laws and policies to curb crop residue burning and monitoring of interventions

Government and institutional support are critical elements in deployment of bioenergy programs in SAARC countries. Depending on the country legislature, the Central government can formulate suitable laws, policies, or orders for prevention of crop residue burning. Accordingly, the Central governments can set up a regulatory body to formulate policies and ensure the implementation of such orders and policies and prevent the practice of crop residue burning. This regulatory body may also set up a regional/ district/ state/ province level monitoring cell for close monitoring of the orders. These monitoring cells and regulatory body can monitor the residue burning after each harvesting season in target areas to ensure effective implementation of laws and measures to curb residue burning.

Additionally, a reward scheme can be designed for the villages that do not burn crop residue and become a role model for other villages. The village panchayats/ heads can submit a proposal or nomination to the local regulatory body and funds will be granted, if proven. These funds can then be used by the village to implement local programs like pellet making, briquetting, composting, biogas plant installation etc.

8.4.4.2 Regulatory Support

There is a lack of regulatory support by Electricity Boards in promoting biomass power generation. It is suggested that the power utilities may be directed to procure a certain percentage of their power needs from biomass plants. Also, power generators could be mandated to procure a minimum percentage of fuel supply from crop residue with high energy content (in form of pellets/briquettes) to co-fire the boilers to generate electricity. This would have a two-fold benefit: (i) low power generating cost by replacing 5-10% of daily coal consumption and (ii) encourage farmers to aggregate their farm wastes for monetary returns.

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10 Annexures

10.1 RPR and Heating Value of Crop Residues

Crop group	Crop	Residue	RPR	Heating value, MJ/kg
Cereals	Rice	Straw	1.5	15.54
		Husk	0.2	15.54
	Wheat	Stalk	1.5	17.15
		Pod	0.3	17.39
	Maize	Cob	0.3	17.39
		Stalk	2	16.67
	Bajra	Cob	0.33	17.39
		Husk	0.3	17.48
		Stalk	2	18.16
	Barley	Straw	1.3	18.16
	Small millet	Straw	1.2	18.16
	Ragi	Straw	1.3	18.16
	Jowar	Cob	0.5	17.39
		Husk	0.2	17.48
		Stalk	1.7	18.16
Oilseeds	Mustard & Rapeseed	Stalk	1.8	17
	Sesame	Stalk	1.2	14.35
	Linseed	Stalk	1.47	14.35
	Niger	Stalk	1	14.35
	Safflower	Stalk	3	13.9
	Soybean	Stalk	1.7	16.99
	Groundnut	Shell	0.3	15.56
		Stalk	2	14.4
	Sunflower	Stalk	3	17.53
Pulses	Tur (arhar)	Stalk	2.5	18.58
	Lentil	Stalk	1.8	14.65
	Gaur	Stalk	2	16.02
	Gram	Stalk	1.1	16.02
Sugarcane	Sugarcane	Bagasse	0.33	20

Crop group	Crop	Residue	RPR	Heating value, MJ/kg
		Top and leaves	0.05	20
Horticulture	Banana	Peel	3	17.4
	Coconut	Frond	4	10
		Husk	0.53	19.4
	Arecanut	Frond	3	18.1
		Husk	0.8	17.9
Others	Cotton	Stalk	3.8	17.4
		Husk	1.1	16.7
		Boll shell	1.1	18.3
	Jute	Stalk	2	19.7

10.2 Biomass Consumption for Power Generation

Sr. No.	Crop	Tons of residue required for production of 1 MW
1	Rice	1.2
2	Wheat	1.4
3	Sugarcane	1.2
4	Maize	1.4
5	Barley	1.3
6	Jute	1.2