CHAPTER 5

CHAPTER 5

DECISION SUPPORT SYSTEM FOR BIOMASS GASIFICATION BASED ELECTRICITY GENERATION

Generalised information on biomass as feedstock for gasification and performance evaluation of gasifiers were presented in Chapters 3 and 4 respectively. Gasifier generated producer gas is used in an alternator integrated heat engine for electricity generation. Thus, the overall biomass to electricity conversion process is conceptualised based on gasifier as the biomass to producer gas conversion system and ICE coupled to a generator as the producer gas to electricity conversion system. The utilization of such an electricity generation process involves various uncertainties which are discussed earlier. This Chapter presents the development of a decision support system (DSS) for such biomass gasification based decentralised electricity generation (DEG). Potential of electricity generation in a typical rural area is examined using the DSS which is also presented in this Chapter.

5.1 Development of DSS

Some of the uncertainties associated with a biomass gasification based electricity generation system at various levels are presented in Fig. 5.1.

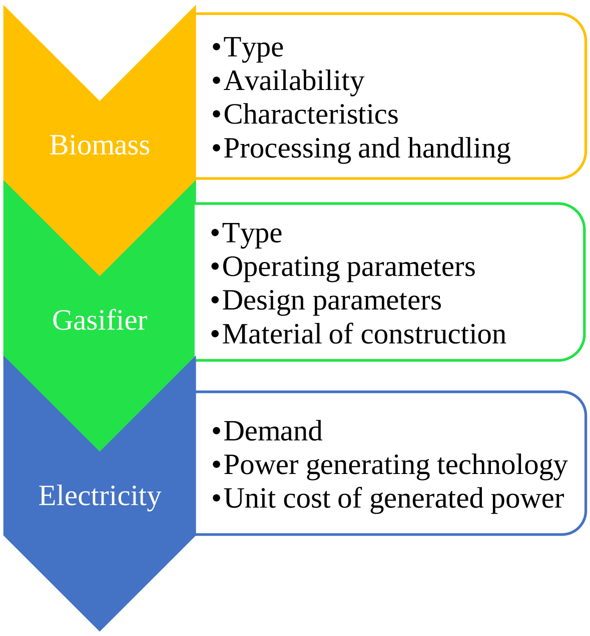

Fig. 5.1 Uncertainties associated with biomass gasification based electricity generation system

Addressing the uncertainties in a manner which would help in taking decisions regarding them is essential for successful planning of the system. In such situations, decision support systems (DSS) have been found to be very useful. DSS consists of a user interface, a database containing appropriate and relevant information, simulation modules capable of manipulating the data and information based on their relationships and an output module which present the results in an easily interpretable form allowing for decision making [1]. Basically, DSS links the information processing capabilities of a management information system or a database containing appropriate and relevant information with modelling techniques and the judgement of users to support decision-making in unstructured situations. The following section discusses the development of a DSS for biomass gasification based electricity generation system.

5.1.1 Architecture of the DSS

The intended utility of the DSS is to have an interface that allows the user to predict the viability of using a gasifier system for a range of energy demand and feedstock supply scenarios or to determine the optimum mix of different aspects (feedstock related parameters, gasifier operating conditions, electricity distribution) where energy demand and feedstock supply issues are known. The variations and decisions possible through the DSS for various scenarios are summarized in Table 5.1.

The interface allows the user to make choices regarding the electrical power requirement, the capacity factor, the type of feedstock, the type of gasifier (in terms of material of construction) and the type of power generation unit. Based on the inputs received the corresponding data of gasification performance is looked up from a gasification performance module. The gasification performance module is created based on the developed biomass gasification models discussed separately in Chapter 4. Also, an economics' module attuned to receive the input parameters and return the levelised cost of electricity (LCOE) is integrated into the DSS. Feedstock type, feedstock pre-processing requirement, gas flow rate, feedstock consumption rate, feedstock availability and levelised cost of electricity are the outputs of the DSS.

The conceptualized framework and basic architecture of the DSS is shown in Fig. 5.2 and Fig. 5.3 respectively.

Table 5.1 Variations and Decisions possible with the DSS for different scenarios

Scenario	Variations possible in the DSS	Decisions possible
(I) Fixed Energy Demand, Fixed feedstock	Capacity factor, gasifier construction material, power generation unit type	**I(a).** Influence of capacity factor enabling decision regarding viability of utilizing the feedstock for the given energy demand. **I(b).** Choice of Gasifier type. **I(c).** Choice of power generation unit type
(II) Varying Energy Demand, Fixed Feedstock	Capacity factor, electrical power, gasifier construction material, power generation unit type	**II.** I(a), I(b), I(c) above for varying energy demand
(III) Fixed Energy Demand, Varying feedstock	Feedstock type, Capacity factor, gasifier construction material, power generation unit type	**III.** Choice of appropriate feedstock along with I(a), I(b) and I(c) above
(IV) Varying Energy Demand, Varying feedstock	Feedstock type, Capacity factor, electrical power, gasifier construction material, power generation unit type	**IV.** All of III for varying energy demand

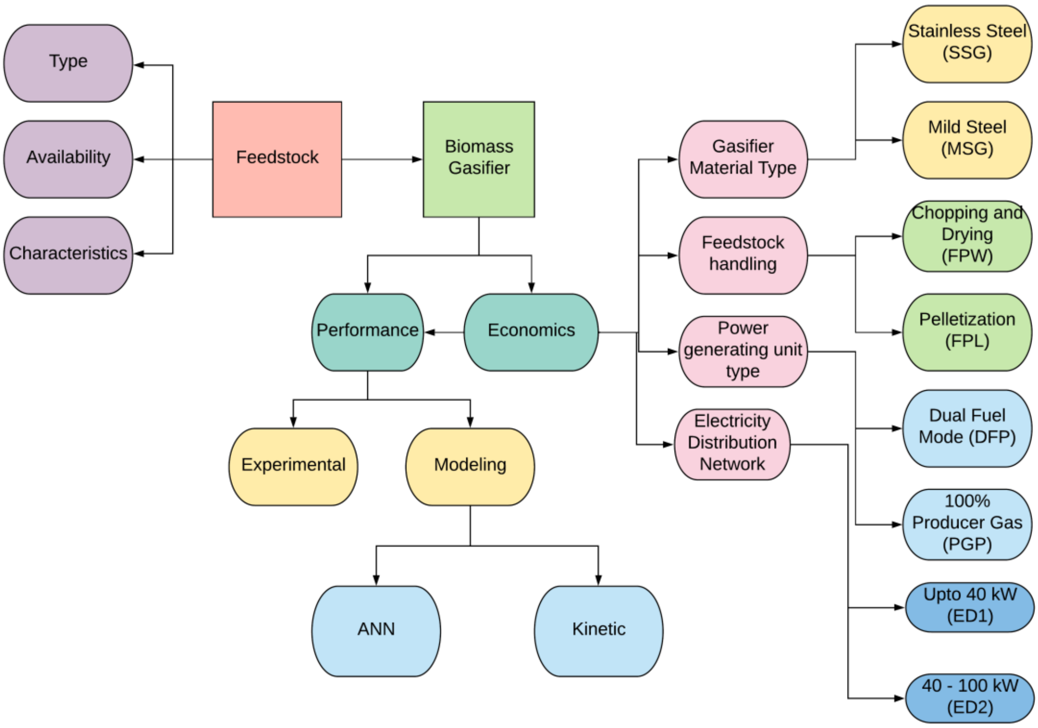

Fig. 5.2 Conceptualized framework of the DSS

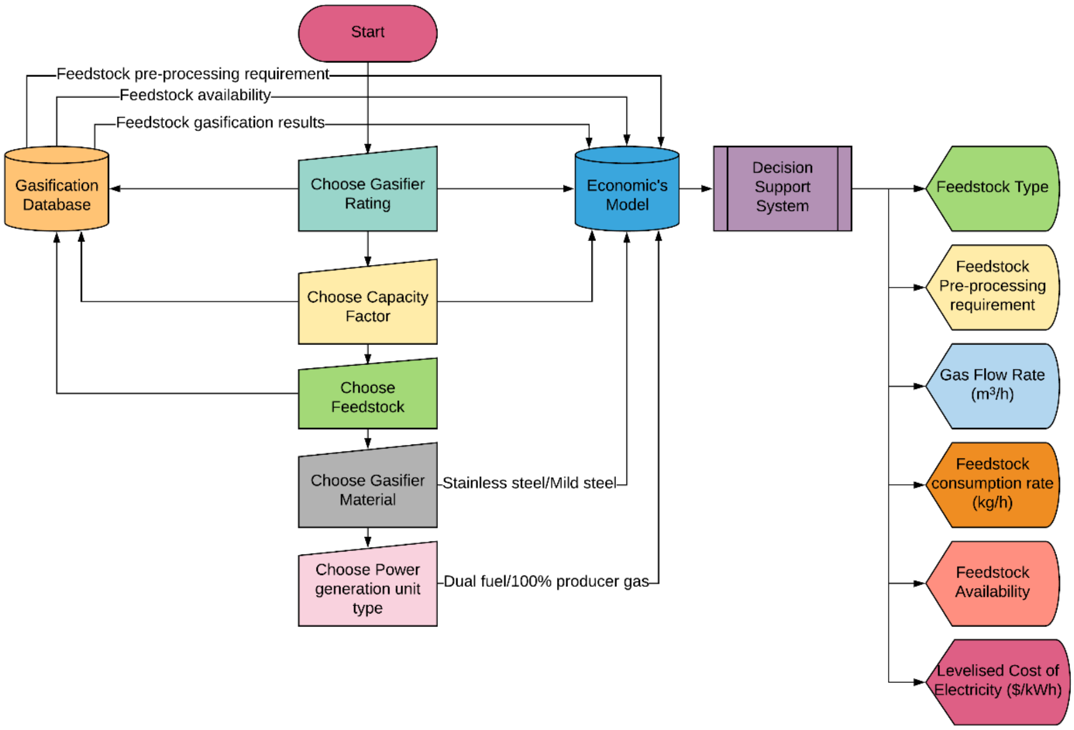

Fig. 5.3 Architecture of the DSS

The user interface, gasification performance results and economic analysis relationships are amalgamated in a Microsoft® Excel workbook as different sheets. The various relationships are programed in the workbook using standard Microsoft® Excel formulas. The user interface of the DSS is shown in Fig. 5.4.

Biomass Gasification Decision Support System

Parameters	Input Values
Choose electrical power requirement (kW)	40
Choose feedstock	Rice Husk Pellet
Choose Capacity Factor	1
Choose Gasifier Material	Mild Steel
Choose Type of Engine	100% Producer Gas

Parameters	Output Values
Feedstock Type	Loose Biomass
Feedstock Pre-processing Suggestion	Feedstock pre-processing required
Gas flow rate (m^3/h)	138
Mass flow rate of feedstock (kg/h)	53
Feedstock availability	Available
Levelised Cost of Electricity ($/kWh)	0.2462

*** User input required in Green Highlighted Cells Only

Fig. 5.4 User interface of DSS

Table 5.2 summaries the range/values of input and output parameters of the DSS. The gasifier rating may be chosen in between 1 and 100 kW (1, 2, 5, 10-100 in steps of 10kW). The capacity factor may be chosen between 0.05-1.00 in steps of 0.05. Choice of 35 different feedstock available in the gasifier performance module. The gasifier material of construction can be chosen to be either stainless steel or mild steel. Also, the power generation unit type can be altered between dual fuel and 100% producer gas mode.

Table 5.2 Input and Output parameters of the DSS

Input parameters	Choice available	Output Parameters	Value
Gasifier rating	1,2,5, 10-100 kW in steps of 10	Feedstock type	Loose/Semi-woody/Woody
Capacity factor	0.05-1.00 in steps of 0.05	Feedstock pre-processing requirement	Required/Not-required
Feedstock	35 different feedstock	Gas flow rate	Gas flow rate in m^3/h
Gasifier material of construction	Stainless Steel or Mild Steel	Feedstock consumption rate	Consumption in kg/h
Power generation unit type	Dual Fuel or 100% Producer Gas	Feedstock availability	Available/Not-available
		Levelised cost of electricity	LCOE in ₹/kWh ($/kWh)

The DSS architecture looks up the gasifier performance module, sends the performance data to the economics module along with the input values and return the values of feedstock type, feedstock pre-processing requirement, gas flow rate, feedstock consumption rate, feedstock availability and levelised cost of electricity. The data flow structure of the DSS is shown in Fig. 5.5. The development of the gasifier performance module and economics' module is discussed in the following sections.

5.1.2 Gasifier performance module

Performance evaluation of gasifier is central in the development of a biomass gasifier based electricity generation unit. The best technique for evaluating a gasifier's performance is through physical experimentation. Experimental studies helps in identification of parameters influencing the performance of a gasifier with a scope to optimize the operating parameters to ensure efficient performance. However, the results of experimental studies are limited to a given system configuration. Determination of optimal operating conditions for different system sizes using different feedstock becomes both time consuming and expensive. This is where mathematical models become handy.

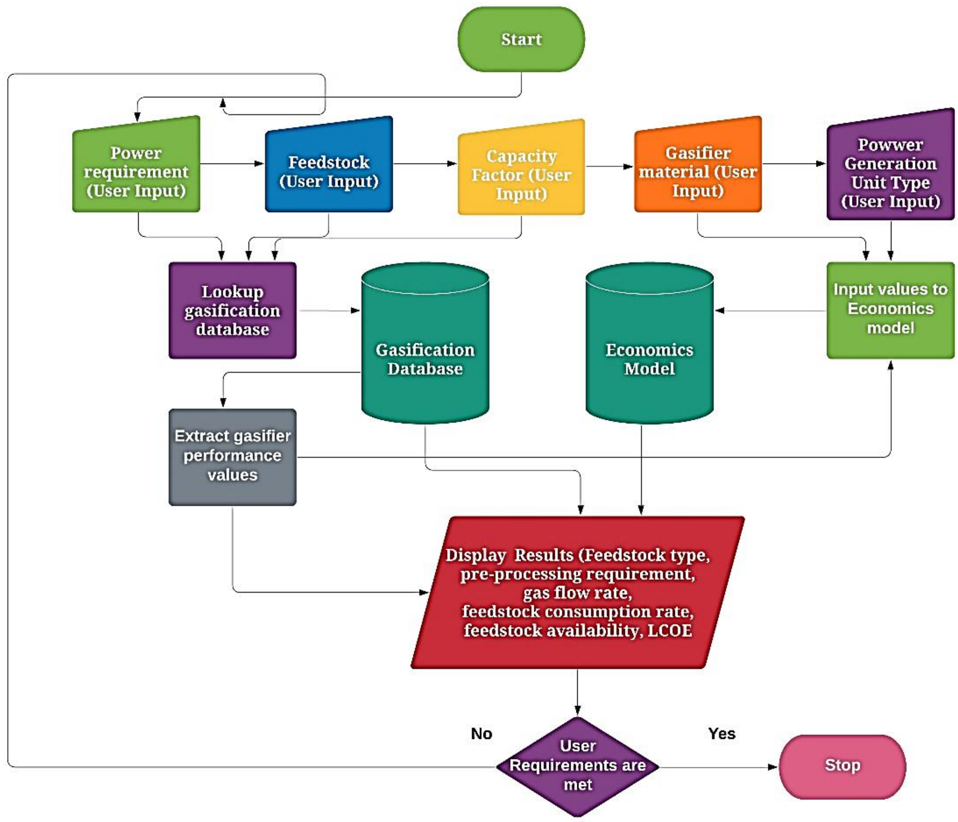

Fig. 5.5 Data flow structure of the DSS

Mathematical modeling is a fundamental and quantitative way to understand and analyze complex systems and phenomena. Mathematical models complement (but does not replace) theory and experiments and integrate them. They are often used in place of experiments when experiments are too large, expensive, or time consuming. Mathematical models of biomass gasification have been observed to give a good representation of the chemical and physical phenomena occurring inside the reactor of a gasifier. A detailed review of the various mathematical modeling techniques used in gasification studies is already discussed in Chapter 2. Also, the two stage modeling approach adopted in the present study are discussed in the previous Chapter. Gasifier performance under a set of possible variable conditions (including feedstock type, gasifier rating and operating conditions) form the output of the gasification performance module.

5.1.3 Economics' module

Economics of power generation is also a key parameter, besides feedstock characteristics and gasifier performance, in planning a biomass gasifier based electricity generation system. A biomass gasifier based electricity generation system comprises of (a) biomass pre-processing unit, (b) biomass gasification unit, (c) electricity generation unit and (d) electricity distribution system. The conceptualized system is presented in Fig. 5.6.

Fundamental to understanding the economics associated with a biomass gasifier based electricity generation system is the electricity production cost. Electricity production cost includes cost of biomass feedstock preparation, conversion, and other procurement and opportunity costs. A systematic approach of economic analysis is developed to allow for analysis of the underlying data and assumptions. Further, the approach allows the comparison of costs of the chosen technology with other electricity generation technologies with scope for identification of key parameters influencing the difference. The analysis is based on the determination of capital cost, annualized cost and levelized cost of electricity (LCOE) as the key indicators.

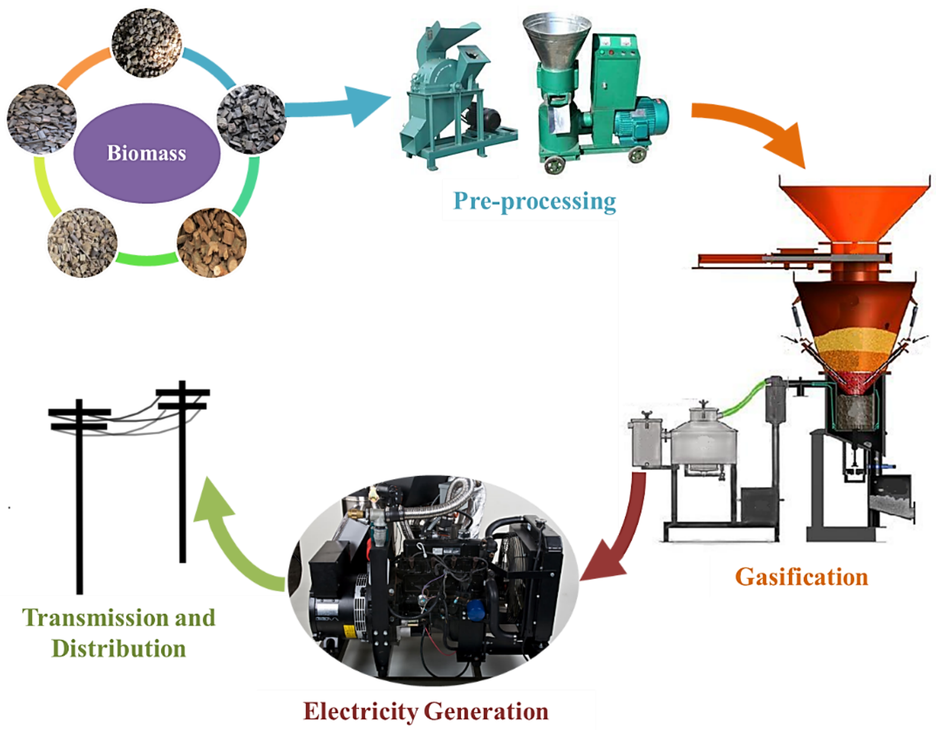

Fig. 5.6 Conceptualized biomass gasification based electricity generation system

5.1.3.1 Capital cost

The overall capital cost of biomass gasification based electricity generation system consists of the cost of feedstock processing and handling unit, the gasification unit, the electricity generation unit, the electricity distribution network and the associated civil works. Realistic costs of the components are considered based on literature survey.

The DSS is capable of analyzing systems of various capacities. However, cost information is available for certain capacities only. Cost of any intermediate size (for which market value is not available) is determined using scale based costing as proposed in literature [2]. Cost changes due to variations in size and time. Both aspects has been standardized as per standard procedures as discussed below. Scale based costing is based on Eq. 5.1.

$$C_B = C_A \left(\frac{S_B}{S_A}\right)^N \qquad \text{----5.1}$$

where C_B is the estimated cost of an equipment having size S_B and C_A is the known cost of the same equipment having size S_A.

$\frac{S_B}{S_A}$ is known as the *size factor* and N is the *scale factor* for that equipment. The scale factor takes into account the relationship between the increase in equipment cost and the increase in capacity. The values of N are taken from literature.

Cost is a time varying parameter. In most cases, the cost at the time of analysis may change from the anticipated cost in the year of purchase. In the event that the market price in the reference year (year of analysis) is not available, the purchase cost are considered as base to estimate the cost for the year of analysis.

In combination, the variability of the cost of equipment with reference to the region and time is also addressed through a standard procedure [2] using Eq. 5.2.

$$C_y = C_x \left(\frac{I_y}{I_x}\right)\left(\frac{E_y}{E_x}\right) \qquad \text{----5.2}$$

where C_y is the cost in current year *y*, C_x is the cost in base year *x*, I_y is the cost index in current year *y* and I_x is the cost index in base year *x*. E_y is the current exchange rate of \$ to ₹ and E_x is the \$ to ₹ exchange rate in base year *x*. Current exchange rate of \$1 = ₹70.23 as on 15/05/2019 is used in the analysis. Many sources exist for cost indices but the more popular one which is readily available is that published monthly in *Chemical Engineering* magazine under "Economic Indicators, Chemical Engineering Plant Cost Index (CEPCI)" [3]. In the analysis the CEPCI has been used as the cost index, the values of which are given in Table 5.3.

Table 5.3 CEPCI values for different years

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019 (January, Final)
CEPCI	525.4	575.4	521.9	550.8	585.7	584.6	567.3	576.1	556.8	541.7	567.5	603.1	617.3

The total capital cost (*C*) is estimated using Eq. 5.3.

$$C = \sum C_i \qquad \text{----5.3}$$

where C_i is the capital cost of item *i*. The capital cost comprises of the cost of the gasifier; power generation unit; civil work; biomass pre-processing unit and cost of electricity distribution network.

Use of stainless steel material for gasifier fabrication has been reported to provide longer life and better performance [4]. However, owing to the low cost of mild steel and fabrication ease mild steel gasifiers are mostly used. Mild steel gasifiers suffers from the drudgery of lower useful life and poor performance [5]. The analysis considers two options of gasifiers based on the material of construction viz. mild steel gasifier (MSG) and stainless steel gasifier (SSG). The electricity generation unit considered are either in dual fuel mode with diesel as pilot fuel and producer gas as main fuel (DFP) or producer gas mode (PGP). Depending upon the nature of the biomass, pre-processing units considered in the analysis are either drying and size reduction for woody and semi-woody biomass (FPW) or palletization for loose biomass (FPL). Two types of electricity distribution network are considered viz. up to 40 kW (ED1) and within 40 – 100 kW (ED2). The capital cost of the items considered in the analysis along with their size, base year of reference and scale factor are summarized in Table 5.4.

Table 5.4 Capital cost of items

Item	Size (Unit)	Cost in ₹ ($)	Base Year	Scale Factor
MSG	40 (kW)	1487963 (21187) [a]	2007	0.6 [b]
SSG	20 (kW)	1906253 (27143) [c]	2019	0.68 [b]
DFP	40 (kW)	870150 (12390) [a]	2007	0.67*
PGP	40 (kW)	1577155 (22457) [a]	2007	0.76*
FPW	0.2 (t/h)	116371 (1657)*	2019	0.77 [d]
FPL	0.2 (t/h)	290963 (4143) [e]	2019	0.55 [f]
Civil works	40 (kW)	200647 (2857) [a]	2007	0.45 [g]
ED1	--	250791 (3571) [a]	2007	--
ED2	--	376222 (5357) [a]	2007	--

[a] Nouni et al. [6]; [b] Whitesides [2]; [c] Veera Power [7]; [d] Liu et. al. [8]; [e] Pradhan et al. [9]; [f] Holmgren [10]; [g] Thunman et al. [11]; * Estimated from [a]

5.1.3.2 Annualized cost

Annualized cost is the annual cost of setting up, operating and maintaining a system over its useful life. Total annualized cost can be estimated by taking into consideration the contributions of the capital costs of subsystems of gasification power plant through respective capital recovery factors based on their useful lives and discount rate, the contribution of operation and maintenance cost and contribution of fuel cost. Total annualized cost (*AC*) is estimated using Eq. 5.4 [6].

$$AC = AC_C + AC_{O\&M} + AC_F \qquad \text{----5.4}$$

where AC_C is the annualized capital cost, $AC_{O\&M}$ is the annualized operation and maintenance cost and AC_F is the annualized fuel cost determined using Eq. 5.5 – 5.8 respectively.

$$AC_C = \sum(C_x \times R_x) \qquad \text{----5.5}$$

where R_x is the capital recovery factor for item x given by Eq. 5.6 [6].

$$R_x = \frac{d_x(1+d_x)^{T_x}}{(1+d_x)^{T_x}-1} \qquad \text{----5.6}$$

where d_x and T_x are the discount rate and useful life respectively for item *x*.

$AC_{O\&M}$ is the annualized operation determined using Eq. 5.7.

$$AC_{O\&M} = \sum(C_x \times F_x) + \left(\sum F_y\right) \times C + (8760 \times C_F \times MP) + C_{WT} \times Ch \quad \text{----5.7}$$

where F_x is the operation and maintenance cost of item *x* as fraction of its respective capital cost (C_x). F_y is the cost of item *y* as fraction of the total capital cost (C). *y* = *I* for insurance, *U* for utilities, *Ad* for administration and *Ms* for miscellaneous expenses respectively. *MP* is the hourly manpower cost for a given gasification plant. C_{WT} is the unit cost of char disposal and *Ch* is the annual char production.

$$AC_F = 8760 \times C_F \times P \times (C_{BM} \times S_{SBC} + C_{Di} \times S_{SDiC}) \quad \text{----5.8}$$

where C_{BM} and C_{Di} are the price of biomass and diesel respectively. S_{SBC} and S_{SDiC} are the specific biomass consumption rate and specific diesel consumption rate (in DFP mode only) respectively.

5.1.3.3 Levelized cost of electricity

The LCOE is determined as the ratio of the total annualized cost to the annual electricity production from the plant (Eq. 5.9) [6].

$$LCOE = \frac{AC}{E_t} \quad \text{----5.9}$$

where E_t is the annual electricity production from the plant given by Eq. 5.10 [6].

$$E_t = P_{rated} \times 8760 \times C_F \left(1 - \frac{P_{ps}}{100}\right) \quad \text{----5.10}$$

where P_{rated} is the rated power of the gasifier, C_F is the capacity utilization factor and P_{ps} is the parasitic load.

5.1.3.4 Model parameters and assumptions

The economic analysis involves the estimation of various parametric values. The following sections describes the various parameters and assumptions used in the analysis.

Biomass cost (C_{BM}) has two components viz. opportunity price to be provided to the farmers and the cost of transportation. An opportunity price of 1505 ₹/t (21.43 $/t) was adopted for the analysis [9]. Transportation cost comprises of fixed cost that is independent of the distance and variable cost depending upon the transportation distance. Fixed and variable transportation costs using a tractor-trailer (2.75 m^3 capacity) were adopted from standard literature [12]. Thus, the overall biomass cost is the sum of the opportunity price, fixed cost of transportation (distance independent) and variable cost of transportation (distance dependent). With respect to electricity generation unit, in case of DFP mode, the cost of diesel is based on the current price. For estimating the labor cost, it is assumed that one skilled labor and one unskilled labor is required for gasification plants of up to 40 kW capacity and two each of skilled and unskilled labor are required for plants within 40 – 100 kW capacity [13]. The cost for waste treatment or disposal of char generated in the gasification unit was estimated based on the survey of a local industrial gasification unit. The annual maintenance cost of gasifier (stainless steel or mild steel material), power generation unit, electricity distribution network and civil works as fractions of their capital cost were adopted from literature. Also, insurance/property tax, utilities cost, management/administration cost and miscellaneous expenses values as fraction of total capital cost were adopted from literature. Table 5.5 summarizes the values of input parameters adopted for the analysis.

There are very few reported values of useful life of gasifier and useful life of DFP mode and PGP mode electricity generating units. The useful life of a gasification plant is, however, dependent on its capacity. In the analysis, useful life of gasifiers has been based on the capacity and material used for fabrication. For capacities up to 40 kW, with stainless steel material the useful life is assumed to be 15 years whereas for mild steel material it is assumed to be 10 years. For capacities in the range of 40 – 100 kW, with stainless steel material the useful life is assumed as 20 years whereas for mild steel material it is assumed as 10 years. The useful life of producer gas engines are found to be less than that of dual fuel engines [6]. The useful life of PGP and DFP units assumed for the analysis are 7 and 10 years respectively. The DFP mode energy generating unit is assumed to operate with 80% producer gas. The conversion efficiency of the power generating unit are considered to be 27% or 23% depending upon the type of the unit either PGP or DFP respectively [6]. The useful life of biomass pre-processing unit, civil works and electricity distribution network are each 20 years. The analysis assumes a parasitic load of 10% resulting from the power consumed in the auxiliary equipment and losses in the distribution network. The analysis is based on an assumed discount rate of 10%.

Table 5.5 Values of input parameters for economic analysis

Item	Unit	Value	Base Year	Source
Biomass cost without transportation	₹/t ($/t)	1505 (21.43)	2019	Pradhan et al [9]
Fixed cost of transportation	₹/t ($/t)	301.3 (4.29)	2016	Golecha and Gan [12]
Variable cost of transportation	₹/(t-km) ($/(t-km))	14.05 (0.2)	2018	Parihar et al [14]
Diesel Cost	₹/L ($/L)	66.72 (0.95)	2019	Current Value (June, 2019)
Labor Cost, Skilled Labor	₹/y ($/y)	136527.12 (1,944)	2018	Parihar et al [14]
Labor Cost, Un-skilled Labor	₹/y ($/y)	98602. 92 (1,404)	2018	Parihar et al [14]
Waste Treatment/Disposal for char/ash	₹/y ($/y)	62034.16 (883.30)		Surveyed
Annual maintenance cost of gasifier as a fraction of its capital cost for stainless steel material		0.05	--	
Annual maintenance cost of gasifier as a fraction of its capital cost for mild steel material		0.10	--	
Annual maintenance cost of power generation unit as a fraction of its capital cost		0.10	--	Nouni et al [6]
Annual maintenance cost of electricity distribution network as a fraction of its capital cost	Fraction	0.03	--	
Annual maintenance cost of civil work as a fraction of its capital cost		0.02	--	
Insurance/Property Tax cost as a fraction of total capital cost		0.04	--	
Utilities cost as a fraction of total capital cost		0.05	--	
Management/Administration cost as a fraction of total capital cost		0.10	--	Parajuli et al [15]
Miscellaneous Expenses as a fraction of total capital cost		0.10	--	

5.2 Planning of biomass gasification based electricity generation in a typical rural area

A representative rural area, Jhawani village in the Bihaguri development block of Sonitpur district, Assam (India) is considered for the present investigation (Fig. 5.7). The study area is geographically located between 26°37'43.637''N (upper left longitude), 92°41'39.35''E (upper left latitude) and 26°38'25.756''N (lower right longitude), 92°40'44.277''E (lower right latitude). To assess and record the life style including the energy usage pattern by the residents of Jhawani, a detailed household survey was conducted during January-February, 2014. The village contains 32 households with a total population of 133. Crop farming and livestock rearing are the two major occupations of the villagers. The electricity consumption by the households in domestic and agricultural activities were recorded.

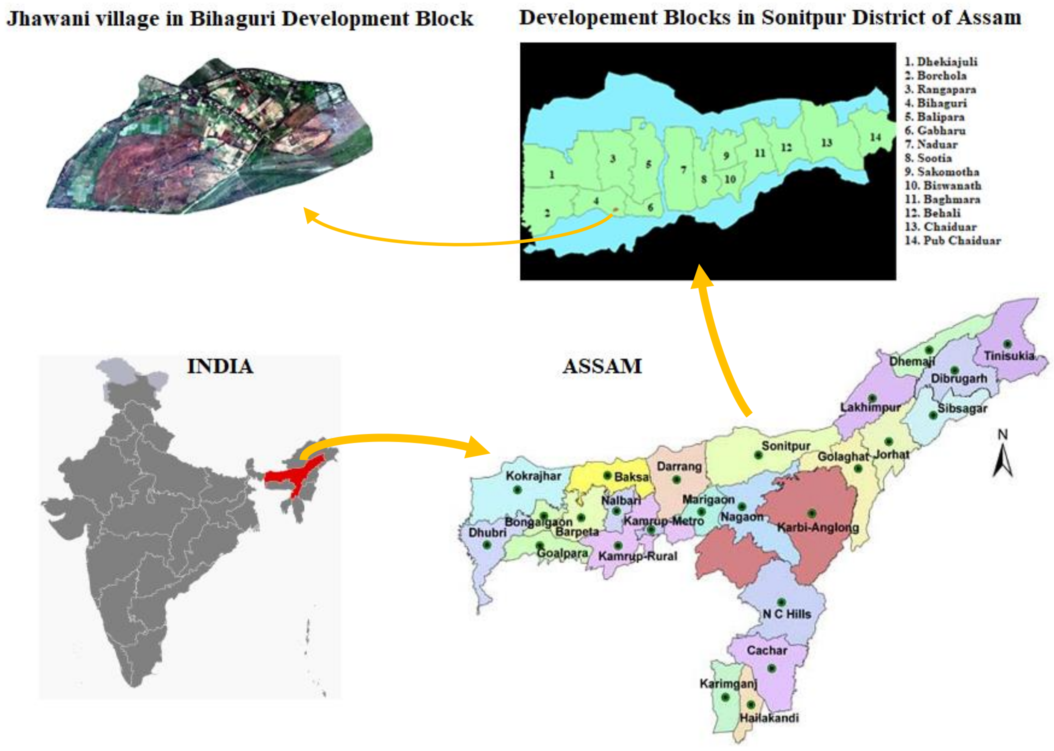

Fig. 5.7 Jhawani village in Bihaguri development block of Sonitpur District of Assam, India

5.2.1 Energy demand estimation of the study area

In a rural community electricity is basically used for lightening and household purpose. Additionally, farm operations, irrigation, small and medium scale industrial operations also consume electricity. For effective planning and operation of an electricity generating system, accurate estimation and forecasting of the energy demand is required. The electrical energy demands of the study area is anticipated from three sectors viz. domestic, agro-industry and irrigation. The overall electricity demand comprising of the different sectors are assessed through a systematic procedure. Domestic load consists of electricity demand for electrical appliances such as light, fan, television, music system and mobile charging. The agro-industry load is based on a rice mill and proposed sugarcane crushers (3 nos.) in the village. In the absence of electricity, the rice mill and the sugarcane crushers derive their power from diesel generators with an estimated annual consumption of 360 litres and 173 litres respectively. The irrigation in the village is based on diesel generator run centrifugal pump at six different locations. For a prevailing cropping pattern, an annual consumption of 277 litres is estimated.

The electricity demand at Jhawani village is assessed based on a desired level of activities of the people. The activity pattern of the villagers, potential agro-processing jobs and irrigation requirements at Jhawani village are considered for the assessment. Considering the different activities, the potential demand schedules are determined for each month of the year and presented in Table 5.6. The village has a peak demand of 15 kW and cumulative annual demand of 61 MWh energy.

Table 5.6 Potential electricity demand of Jhawani village

Month	Peak demand, kW	Total demand, kWh	% share		
			Domestic	Agro-industry	Irrigation
January	12.33	4045.50	29.21	53.64	17.15
February	13.41	5188.80	19.32	68.61	12.08
March	13.93	6280.70	26.79	62.17	11.05
April	14.70	4772.25	41.93	44.00	14.07
May	14.14	5720.12	55.35	32.52	12.13
June	14.14	5333.10	63.57	11.25	25.18
July	14.14	5510.87	63.57	11.25	25.18
August	14.14	5783.98	60.57	21.44	17.99
September	14.14	5597.40	60.57	21.44	17.99
October	14.14	5724.77	56.46	20.55	22.99
November	13.10	3315.00	34.50	45.25	20.25
December	13.10	3425.50	34.50	45.25	20.25
Peak load : 15 kW					

The present analysis tries to investigate the scope of biomass gasification as an option of electricity generation for the study area. It is anticipated that the energy demand of the study area will gradually increase every year as is the case worldwide.

The analysis is based on a forecasted energy demand at the end of the useful life of the biomass gasification based electricity generation system. Considering an useful life of 15 years, the peak energy demand of the village is forecasted to be 40 kW based on an annual electricity demand increase rate of 6.5% [16].

5.2.2 Biomass resource assessment of the study area

Feedstock for the biomass gasification based electricity generation system is identified based on their availability. Varieties of feedstock are available which can be utilized for gasification. As already discussed in Chapter 3, the available feedstock can be broadly categorised into woody, semi-woody or loose biomass. Crop farming being a major occupation of the villagers, agro-residue biomass is a major feedstock available in the area. An estimation of the biomass resource availability in the study area is essential in gaining an insight into the energy generation potential of the region. There is spatial as well as temporal variation in the availability of biomass feedstock within the study area. So, proper assessment is necessary to gain a proper understanding of the feedstock availability. The biomass resource availability at Jhawani village was assessed and mapped using high resolution IRS P6 LISS III satellite imagery in ArcGIS software following a methodology adopted by Brahma et al [17]. The details of the images collected from National Remote Sensing Centre (NRSC), Government of India are given in Table 5.7.

Table 5.7 Details of remote sensing images

Item	Details
Satellite	IRS P6
Sensor	LISS III
Swath	23.5 m
Spatial resolution	141 km ×141 km
Spectral bands (microns)	B2 (0.52–0.59); B3 (0.62–0.68); B4 (0.77–0.86); B5 (1.55–1.70)
Acquisition dates (Path, Row)	November, 2008 (111, 52)

The images were processed to adjust brightness, contrast and transparency for better display and delineation of features. 1:50000 Survey of India topographical maps along with UTM projection system were used to georeference the images. Interpretation and delineation of land use classes was based on the guidelines for

IRS-P6 LISS III image interpretation provided by NRSC, India [17]. The resultant map was then utilised for making spatial analysis of feedstock availability. The total geographical area was delineated into land use classes viz. reserved land, cropland, grassland, community land, tree cover, wetland and settlement. The percentage share of the land use classes are summarised in Table 5.8.

Table 5.8 Share of land use classes

Land use class	Area, ha	% share
Cropland	47.21	27.20
Community land	19.33	11.14
Grassland	22.44	12.93
Reserved land	69.46	40.01
Tree cover	10.65	6.14
Wetland	4.27	2.46
Settlement	0.12	0.07
Unclassified	0.11	0.06
Total	173.59	

The land use and land cover of the area is represented in Fig. 5.8. It is observed that reserved land (40%) has the highest share followed by cropland (27%) in the area. The agro-residue biomass of the area is identified to be a major source of feedstock for gasification based electricity generation system for the area.

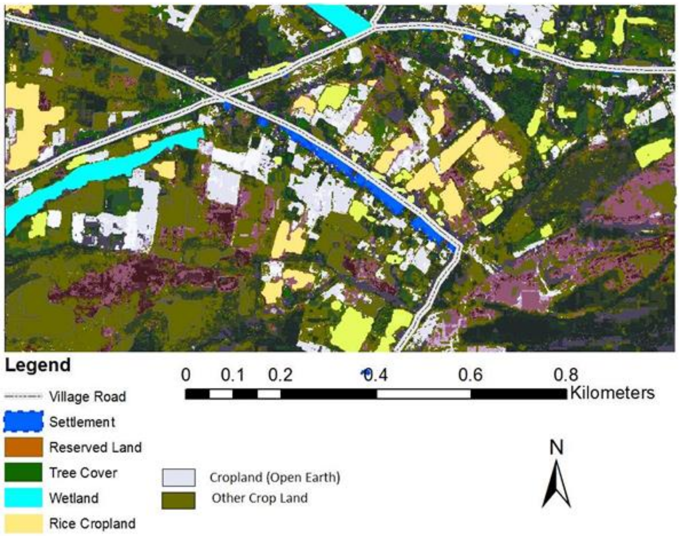

Fig. 5.8 Land use and land cover of Jhawani village

The availability of agro-residue of the area was estimated. Agro-residue biomass (ARB) from major crops cultivated in the area were considered. The spatial availability of ARB was estimated based on the methodology reported by Hiloidhari et al [18]. The theoretical agro-residue biomass availability is calculated using Eq. 5.11.

$$TARB(j) = \sum_{i=1}^{n} R(i,j) \times Y(i,j) \times A(i,j) \qquad \text{----5.11}$$

where TARB(j) is the total theoretical agro-residue biomass availability at j^{th} location, tonne; *R(i,j)*, *Y(i,j)* and *A(i,j)* are the residue production ratio, yield (tonne ha^{-1}) and area (ha) of i^{th} crop at j^{th} location respectively. The value of *R(i,j)* for the available crops of the area have taken from available literature [18,19] and given in Table 5.9.

Table 5.9 Residue production ratio of different agro-residues

Crop residue	RPR
Rice Straw	1.5
Rice husk	0.2
Sugarcane bagasse	0.33
Mustard Straw	1.8
Jute stalk	2
Red lentil straw	1.8
Black gram straw	1.1
Green gram straw	1.1

Eq.5.11 gives the theoretical availability of agro-residue but practically the whole amount of residue is not available for utilization. This is due to the competitive uses, techniques of harvesting and threshing, and methods of collection of remaining lot. It is observed that the farmers use the agro-residue, particularly rice straw as feeds for livestock and also as fuel. There are also instances of other uses of the agro-residue like compost making and papermaking [20]. Thus, the practically available amount of agro-residue is lesser than the theoretical value. To incorporate the uncertainties associated with the competitive uses, techniques of harvesting and threshing, and methods of collection the practically available agro-residue is estimated by multiplying Eq.5.11 by a residue availability factor, *F(i,j)*. The value of *F(i,j)* considered for the study were 50% for rice straw and 80% for other remaining agro-residues.

The availability of biomass feedstock based on the discussed methodology is summarised in Table 5.10. It is observed that the Dhaincha is the predominant biomass of the region followed by rice straw, rice husk, sugarcane bagasse, mustard straw and jute stalk. In addition to the agro-residue biomasses, about 3 tonnes of bamboo (varieties namely *Bambusa balcooa, Bambusa tulda, Bambusa pallida*) is also available in the village. Rice straw is the second largest available resource in the study area. Rice straw as a feedstock for biomass gasification is widely used in Fluidised Bed Gasifiers. The present investigation being based on downdraft gasifiers, rice straw is not considered as a feedstock in the analysis. Biomass gasification based electricity generation using dhaincha, rice husk pellet, bagasse pellet, jute stalk pellet and bamboo were considered for the present analysis. Also, a transportation distance of 3 km based on the distance of farthest farm (biomass collection point) from the community land (probable location of the electricity generation system) is considered for the analysis.

Table 5.10 Biomass feedstock availability in Jhawani village

Resource	Availability, kg/annum
Dhaincha	33703.80
Rice Straw	20768.40
Rice husk	2307.60
Sugarcane bagasse	12861.90
Mustard Straw	11281.40
Mustard Husk	1251.41
Jute stalk	8241.75
Red lentil straw	2337.87
Red lentil Husk	425.07
Black gram straw	2273.82
Black gram husk	412.77
Green gram straw	274.00
Green gram husk	49.82

5.2.3 Comparative analysis of different options of biomass gasification

The forecasted electricity demand of the area is 40 kW as discussed in Section 5.4.1 The developed DSS has been utilised to investigate the scope of biomass gasification based decentralised electricity generation option for the area. The DSS returns the values of feedstock type, feedstock pre-processing requirement, gas flow rate, feedstock consumption rate, feedstock availability and levelised cost of electricity for a given choice of electrical power requirement, the capacity factor, the type of feedstock, the type of gasifier (in terms of material of construction) and the type of power generation unit. Considering the electrical power requirement of 40 kW and a capacity factor increasing at the rate of the annual increase in the electricity demand i.e. 6.5%, the LCOE for different configurations of the gasifier material and power generation unit utilizing the identified feedstock were estimated. The results are shown in Fig. 5.9.

It is observed that the use of stainless steel gasifiers resulted in higher LCOE values in all cases despite having higher useful life and lower maintenance cost than mild steel gasifiers. Also, variation in the type of electricity generation units (DFP or PGP) had very little influence on the LCOE. In case of Rice husk pellet, lowest LCOE (17.56 ₹/kWh) was observed in the MSG+DFP configuration whereas in case of the other four feedstock the lowest LCOE (14.05, 16.15, 16.15 and 14.75 ₹/kWh in the case of Dhaincha, Bagasse pellet, Jute stalk pellet and Bamboo respectively) was observed in the MSG+PGP configuration. Also, use of pelletized feedstock resulted in a higher LCOE in comparison to semi-woody biomass (Dhaincha and Jute stalk) considered in the analysis.

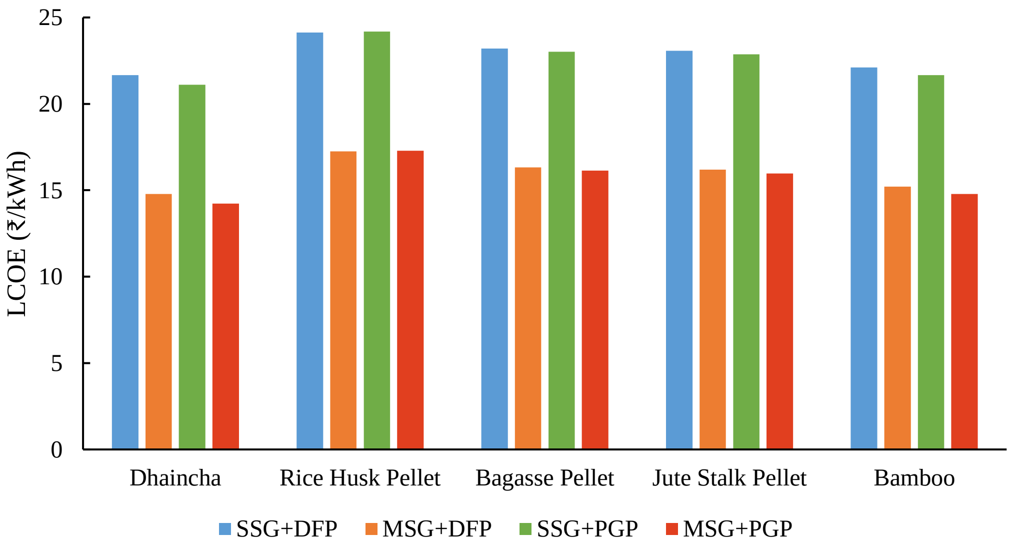

Fig. 5.9 Variation of LCOE (₹/kWh) under different configurations

It is anticipated that other electricity generation techniques viz. conventional grid, solar and diesel engine generator are also capable of supplementing the requirements of the region. There are variations in the unit cost of electricity of different generating technologies depending upon the technology, region, capital and operation & maintenance costs, and the efficiency of the technology. In order to get a comparative picture of the different possible systems of electricity supply to the region the LCOE of the systems (Grid electricity, Solar PV rooftop residential, Solar PV commercial and Diesel generator) were compared with LCOE of biomass gasification based electricity generation in the MSG+PGP configuration utilizing Dhaincha (lowest LCOE scenario). The current domestic LT electricity tariff rate (<5kW) of Assam, India [21] was considered for the analysis. In absence of reported LCOE values of Solar PV rooftop residential and Solar PV commercial for the region, the corresponding reported national values (adjusted to current price, considering changes in the exchange rate) were considered [22]. The LCOE of diesel generator based electricity generation in the region is estimated to be 21.07 ₹/kWh. The results of the comparison are shown in Fig. 5.10.

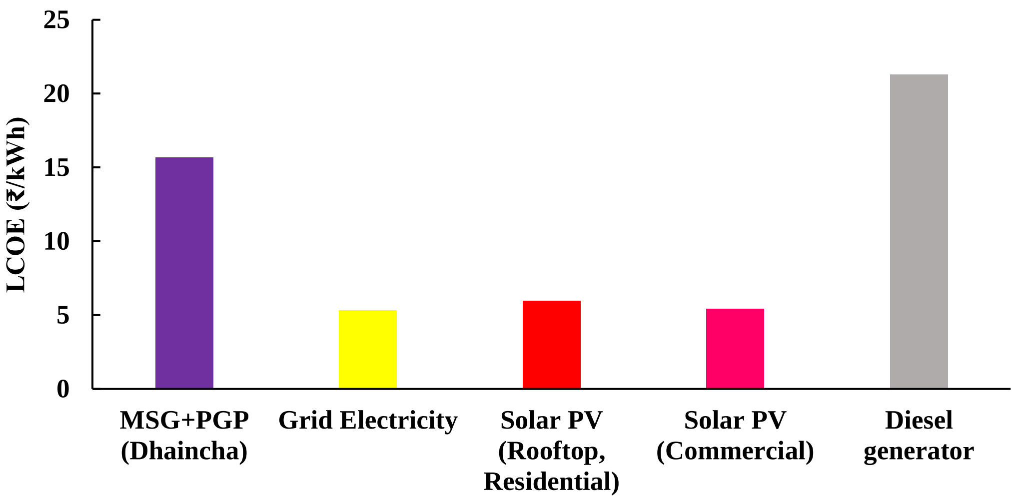

Fig. 5.10 Variation of LCOE (₹/kWh) with different generation systems

The utilisation of biomass gasification based electricity generation for the study area in the MSG+PGP mode utilizing Dhaincha results in a LCOE value (1545.06 ₹/kWh) less than that of diesel generator (21.07 ₹/kWh). Grid electricity price is lowest (5.34 ₹/kWh) provided grid extension to the region is possible. Also, Solar PV (Rooftop, Residential) and Solar PV (Commercial) are viable options for the region having low LCOE values (5.97 and 5.41 ₹/kWh respectively). However, temporal intermittency of solar radiation along with varying climatic conditions necessitates additional storage requirements. Thus, solar PV and biomass gasification based hybrid electricity generation can be a potential option for the region. Further investigation in this area is required. Biomass gasification based electricity generation is a viable option in the area. Identification of key factors influencing the LCOE of the biomass gasification based system is useful for further understanding of the above comparison.

The LCOE varies with the load of the electricity generation system. The variation in the LCOE for different configurations utilizing woody and semi-woody feedstock (Dhaincha and Rice husk pellet) and for different ratings of the gasification system is shown in Fig. 5.11. It is observed that the LCOE decreases with the increase in load or rating of the gasification plant. This, in turn, is related to various techno-economic parameters of the system. In order to analyze the variations in the LCOE with the variations in terms of capital cost, fuel cost, net efficiency and capacity factor a sensitivity analysis with Dhaincha and Rice husk pellet as feedstock was carried out.

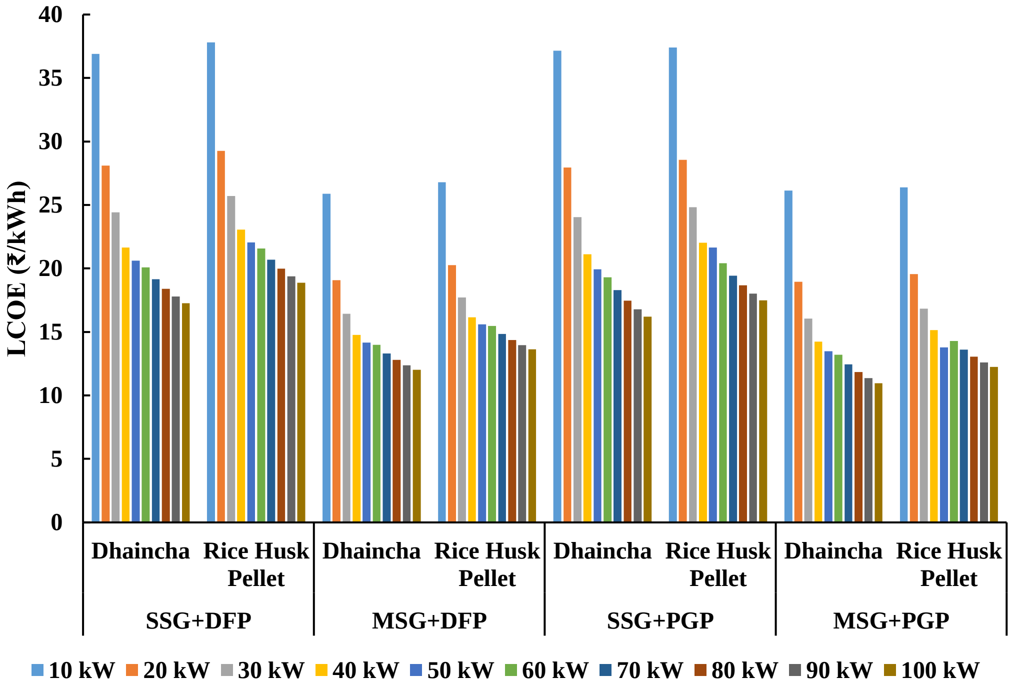

Fig. 5.11 LCOE at different ratings and configurations using Dhaincha and Rice husk pellet

Fig. 5.12 represents the percentage change in LCOE value with percentage change in the values of capital cost, fuel cost, net efficiency and capacity factor for a power rating of 40 kW utilizing Dhaincha as feedstock in the MSG+PGP configuration. The capacity factor dominates the change in LCOE. The plant should be operated at the maximum capacity factor for lower LCOE. Net efficiency was the next influencing parameter. Fuel cost was the third most influencing parameter. There is possibility of controlling the LCOE value by creating a consensus among the farmers of the region who are also the electricity users to ascertain an optimum fuel cost which does not drastically effect the income of the farmers and also helps in bringing down the LCOE value. Capital cost was the next most influencing variable. Although a user does not have control over the capital cost, the designers of the associated sub-systems of the plant may be motivated to look for techniques or materials to bring down the capital cost. The analysis was also carried out using Rice Husk Pellet as feedstock as shown in Fig. 5.13.

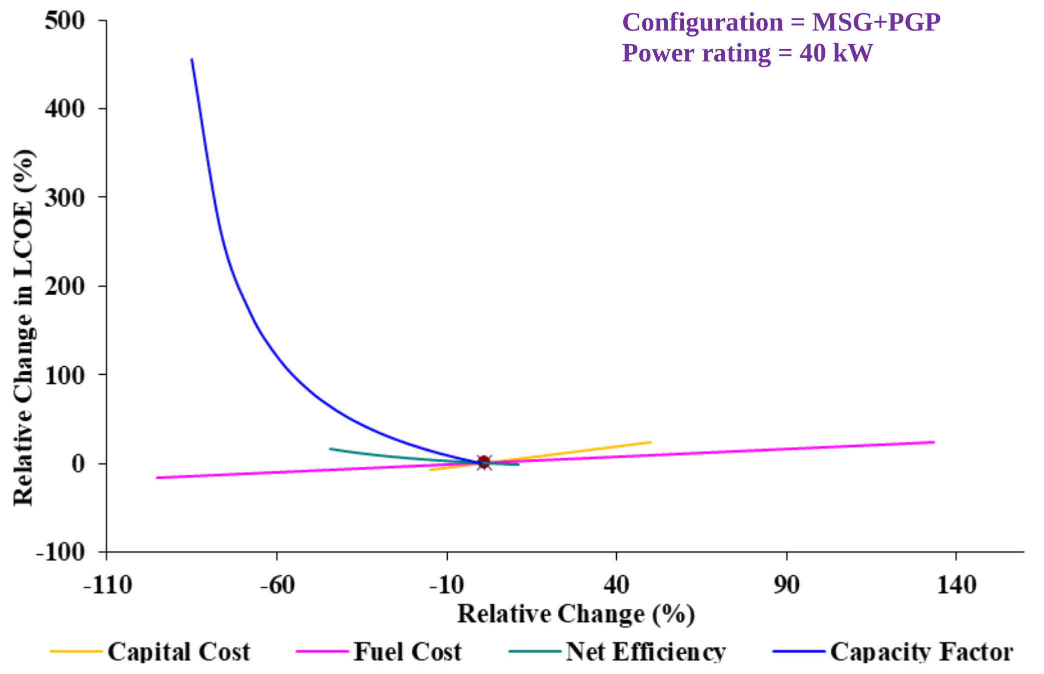

Fig. 5.12 Influence of techno-economic parameters on LCOE using Dhaincha as feedstock

In order of degree of influence the factors are ranked as capacity factor, net efficiency, fuel cost and capital cost while considering rice husk pellet as feedstock. This trend is different than in the case of Dhaincha discussed earlier. There is difference of net efficiency in the two scenarios. The net efficiency is the product of the gasification efficiency and efficiency of the power generating unit. There is possibility of determining operating conditions for the gasification system based on the models used in the study. The feedstock under consideration is a pelletized feedstock having pre-processing requirements. Apart from fixing an optimum sale price for the farmers, as discussed above, research is also required to suggest optimization of cost of biomass pellet production.

Biomass gasification integrated power generation is one of the feasible option of DEG. The uncertainty regarding the selection of feedstock and technology for different phases of energy conversion and generation has been reduced using a simulation integrated DSS. Based on the data concerning the power requirement, feedstock characteristic, feedstock pre-processing, gasifier performance, electricity generation and distribution the most economic options of technology can be identified using the DSS.

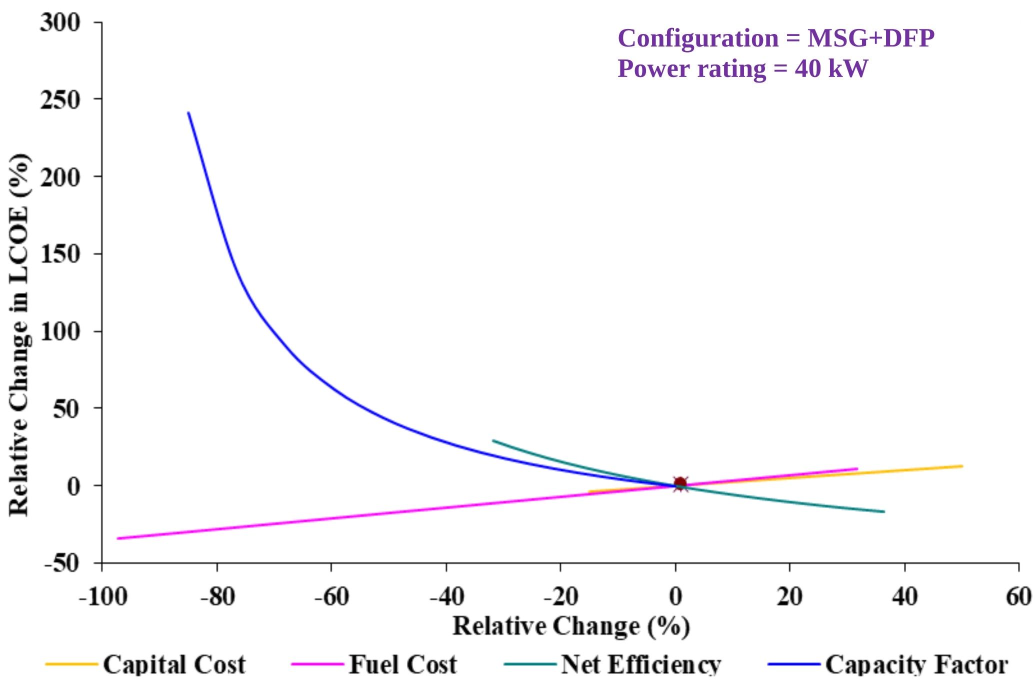

Fig. 5.13 Influence of techno-economic parameters on LCOE using Rice Husk Pellet as feedstock

Renewable based electricity generation has been a prime requirement for most the nations including India. India has raised its target of achieving 175 GW electrical power from renewable resources to 227 GW by 2022 [23]. Of this 10 GW is targeted from biomass power. In order to achieve these targets, electricity distribution companies (DISCOMs) of different states are mandated to source a percentage of their generation and distribution from renewable energy under the categories of Solar and Non-solar known as the Renewable Energy Purchase Obligation (RPO). Ministry of Power, Govt. of India has mandated a RPO of 21% (10.5% from solar and 10.5% from non-solar, uniform for all States and Union Territories) by the financial year 2021-2022 [24]. Biomass gasification based electricity generation is expected to be a key contributor in supplementing the RPOs. Increase in share of biomass gasification based electricity generation is required to ensure the transition enabling the achievement of energy access to all, improving energy security and meeting climate related targets by reducing GHG emissions. However, policy interventions are required for promotion and development of this area which by far has only 13% contribution in the total installed off-grid capacity [25]. Already a variety of policy options have been deployed but in order to scale-up, effective and comprehensive policies are to be devised. Output of the present work is expected to be useful for formulation of policy as well as for assessment in a realistic framework of thermal conversion and power generation using biomass feedstock.

Supply chain of the biomass is a very critical issue. There are many examples where in spite of feasibility of technology and economics the system failed due to uncertainty in the biomass supply. For an expected electricity generation price, as estimated by the DSS, the investor will be attracted towards the system. Farmers or local entrepreneurs will be encouraged to join if the certainty with a given level of price is known to them in advance. Also, variation in the price with variation in the feedstock will be known to them through the DSS. This understanding will help the farmers, the investors as well as the power distribution company to develop a comprehensive and transparent plan of the system.

In respect of thermal conversion, the designer would know the effect of the design on the final cost of the electricity generated using the unit. The operators will also be capable of taking decisions regarding the operating conditions resulting in optimised cost of generated electricity. Distributors, who try to manage the resources and run the system at an optimum level, will be supported by the DSS in taking decisions regarding the variabilities of the system throughout the demand-supply chain.

Local community and/or individual ownership of the system, depending upon the scale, is to be promoted. Training programmes are to be conducted targeting the local population as employees for the project.

The LCOE of the plant is influenced by the design and operating conditions of the various components (feedstock processing, biomass gasification and electricity generation). Research interventions are required to ensure improvement in the efficiencies of the components. Also, research is required in respect of optimization of design and material of construction of the components in order to increase the useful life of the components and also decrease the capital costs. Such research activities are to be amply promoted and supported by Governmental policies and regulations.

5.3 Summary

Development of a DSS for biomass gasification based electricity generation is presented. Utilization of the DSS for investigating the scope of biomass gasifier as a rural energy option is also presented. The DSS was found to be useful in visualizing the effects of various uncertainties associated with the system. The results of the DSS based analysis for the study area helped in establishing a suitable configuration of gasifier and power generation unit type resulting in the minimum LCOE.

The analysis shows that out of the five biomass feedstock taken into account, using Dhaincha leads to the lowest LCOE in the MSG + PGP configuration. Use of SSG leads to a higher LCOE in all cases. Use of biomass feedstock in the MSG+PGP configuration is an option for biomass gasification based power generation in the study area. Factors affecting the LCOE were analyzed. Utilization of the DSS in supporting policy interventions to augment the development of biomass gasification based electricity generation are also highlighted.

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