

ENERGY AND ECONOMIC ANALYSIS

5.1 Introduction

The present thesis also emphasizes comparative energy and economic analysis of different vegetable oil plants in biodiesel production. The objective of this analysis is to select the vegetable oil plants for biodiesel production. For this purpose, eight different vegetable oil plants are selected, i.e. Jatropha, Mahua, Neem, Palm, Coconut, Karanja, Jojoba and Tung. The energy analysis conducted through a life cycle assessment (LCA) approach. It includes cultivation of crops, extraction of oil from seeds, biodiesel production, and effects of this product and process on the environment. It also consists of the evaluation of global issues such as CO₂ emissions for comprehensive life cycle analysis. To understand the advantages of biodiesel, it required to compare the life cycle emissions of biodiesel with conventional diesel. In this study evaluate the effect of greenhouse gas emissions, biodiesel energy's balance and its impacts on the generation of air, water, and solid waste pollutants.

5.2 Methodology

According to the ISO standard [229], the study has been conducted to evaluate the energy life cycle assessment of vegetable oil plants for biodiesel production. It comprises the cultivation of crops, extraction of oil, and production of biodiesel. The cultivation phase includes several energy inputs such as human labour, agricultural machinery, fossil fuel, fertilizer, chemical, seed, electricity, and water for irrigation. The oil extraction phase

comprises the different activity; seed decortications, expelling of oil from seeds, and filtering of oil, for that required electricity and needed human labour. The biodiesel production phase includes the esterification and transesterification process, for that needed the several energy inputs such as alcohol (methanol), catalyst (acid-H₂SO₄ and base-NaOH/KOH), electricity and, human labour. The energy output includes biodiesel, crude glycerol (from biodiesel production phase) and seed/oil cake (from oil extraction phase). From various energy inputs, the non-renewable energy consists of inorganic fertilizers, insecticides, diesel, alcohol (methanol), catalyst (NaOH and H₂SO₄), machinery (transesterification unit, expeller, decorticator, and oil filter) and electricity, and renewable energy includes the human resources, organic fertilizers, and water.

Assumption: The following parameters were considered during the estimation of energy inputs, outputs and economic analysis of vegetable oil plants in biodiesel production.

- Longer life of plants (cultivated for long time).
- Cultivation time 20 year.
- Hundred percent plants survival are considered.
- Plantation area is 1 hectare.
- All the input and output are converted into its corresponding energy (table 5.1).
- The inputs are chemicals, fertilizers, man power, machinery, fossil fuel, alcohol, catalyst, electricity etc.
- Biodiesel is the final product.
- Seed cake and crude glycerol are the co-products.
- The calculation begins from plant nursery
- Seedling of plants per hectare

- Plantation/transplantation per hectare
- Considered energy consumption during growth of plant
- Harvesting or seed collection per hectare
- Considered 100% efficiency of expeller
- Esterification and trans-esterification for biodiesel production
- The summation of all energy inputs provide us the total energy input.
- The sum of energy is compared with energy presented in the fuel.
- During the life cycle analysis considered only indirect energy given to system.
- The direct energy consumed by plant like energy contained in the soil and solar energy is not considered.

Table 5.1: Energy equivalent coefficient of inputs and outputs

Items (Unit)	Energy equivalent (MJ/unit)	Items (Unit)	Energy equivalent (MJ/unit)
A. Cultivation		B. Oil Extraction	
1. Human labour (h)	1.96 [117]	1. Human labour (h)	1.96 [117]
2. Machinery (h)	[240,241]	2. Electricity (KWh)	11.93 [244,246]
a) Tractor	93.6	3. Diesel (L)	47.8 [243]
b) Self propelled	87.63	C. Biodiesel Production	
c) Other machinery	62.7	1. Human labour (h)	1.96 [117]
3. Chemical (kg)	[242, 243]	2. Machinery (h)	8 [243]
a) Herbicides	238	3. Electricity	11.93 [244,246]
b) Insecticides	101.2	4. Methanol (kg)	33.67 [201,247]
4. Diesel (L)	47.8 [243]	5. Catalyst (kg)	
5. Fertilizers (kg)	[242, 244]	a) KOH	19.87 [201,248]
a) Nitrogen	66.14	b) NaOH	23.30 [199]
b) Phosphate (P ₂ O ₅)	12.14	c) Hydrochloric Acid	21 [201]
c) Potassium (K ₂ O)	11.15	d) H ₂ SO ₄ (L)	3 [199]
d) Sulphur (S)	1.12		
e) Farmyard manure	0.3		
6. Poly bag usage (Number)	0.69 [199]		
7. Water for irrigation (m ³)	1.02 [240, 245]		
8. Electricity (kWh)	11.93 [244]		

5.3 Data Collection

The detailed information about various inputs during the cultivation of Jatropha, Mahua, Neem, Palm, Coconut, Karanja, Jojoba and Tung has been taken from various agricultural site and research paper for one hectare plantation. Parallel experiments were undertaken in CERD lab at IIT (BHU) Varanasi, India for different biodiesel related inputs/outputs and properties. The table 5.2 shows the information collected for energy and economic analysis. The data has been collected in three phases; crop cultivation, extraction of oil and production of biodiesel.

5.3.1 Cultivation data collection

The primary stage of life-cycle assessment is the cultivation of crop for biodiesel production. It includes several activity such as seeding (by seeds, stem cutting, sowing in nursery beds etc.), preparation of pit and field (tilling and weeding), plantation and transplantation practices, poly bag uses, fertilizers application (urea during nursery, nitrogen, phosphorous, potassium, Di-ammonium phosphate (DAP), cow-dung etc.), intercropping, irrigation, weeding, pruning and harvesting. The agricultural input data for Jatropha [78, 230], Mahua [79, 231], Neem [80, 232], Karanja [81, 233], Jojoba [234], Tung [235], Coconut [236, 253] and Palm [237, 238] oil are adopted from National Oilseeds & Vegetable Oils Development Board (Ministry of Agriculture, Govt. of India). The production of seeds from plants depends on its gestation period and maturity time. The mature tree produces the maximum yield. The gestation period of Jatropha, Mahua, Neem, Palm, Coconut, Karanja, Jojoba and Tung are 1-2, 8, 5, 3, 6, 4, 4 and 4 years respectively [78-81, 230-238]. Table 5.3 shows the plants details, percentage oil in seeds, biodiesel conversion efficiency, and calorific value.

5.3.2 Oil extraction data collection

The second stage of energy life-cycle assessment for biodiesel production is the oil extraction from seeds. The decortications, seed pressing, and oil filtrations processes are carried out simultaneously during the oil extraction. The oil extraction units (decorticator, expeller and filter press) have been installed in CERD lab of IIT (BHU) Varanasi. The harvested fruits are initially decorticated, i.e., extraction of the seeds from the fruit shell. The decorticator is available of 1.5 kW with a capacity of 150 kg per hour. The oil extraction from seed by screw press expeller of 5.5 kW with a capacity of 50 kg per hour. The extracted oil filters by filter press of 1.5 kW with a capacity of 600 kg per hour. The crushing of seeds produces the main-product is oil, and a by-product is seed/oil cake.

Table 5.2: Information collected for energy analysis

A. Cultivation	Data
Nursery practices	Use of poly-bag, water, fertilizer,
Preparation of field	Use of machinery
Field inputs	Seedlings per hectare, use of fertilizer
Plantation management	Irrigation, fertilizer, weeding, and harvesting practices
Yield	Seeds kg/ha /yr
Origin of inputs	Machinery, fertilizer
Transport distances	Machinery, fertilizer, Seeds
B. Oil Extraction	Data
Extraction rate	Oil per kg of seed
Oil press	Capacity and energy consumption
Filter Press	Capacity and energy consumption
By-product and use	Seed-cake per kg of seed
C. Biodiesel production	Data
Trans-esterification unit	Capacity and energy consumption
Conversion efficiency	Biodiesel % / kg oil
Esterification and trans-esterification	Alcohol and catalyst use
By-product	Glycerine

Table 5.3: Plants details, biodiesel conversion efficiency and calorific value

Vegetable plants	Plants per ha	Maturity Time (Years)	Oil Contents (% wt/wt)	Conversion Efficiency (% wt/wt)		Calorific value (MJ/kg)		
				Biodiesel	Glycerine	Biodiesel	Glycerine	Cake
Jatropha [78, 197, 203, 204, 230, 249]	2500	6	38	97.00	18.00	37.27	25.60	22.00
Mahua [79, 128, 231, 250]	200	14	30-40	98.00	18.00	37.00	18.50	19.97
Neem [80, 232, 251, 254, 255]	400	13	20-30	95.00	15.00	39.60	18.50	21.84
Coconut [236,252, 253]	177	10	63-65	98.4	11.00	38.10	18.5	19.30
Palm [237-238, 257-259]	143	11	30-60	92.00	11.00	37.20	18.05	19.30
Karanja [81, 227, 233, 259]	500	11	27-39	97.00	20.00	37.98	18.50	14.30
Jojoba [233, 260]	2500	13	50	97.00	18.00	39.862	18.50	21.84
Tung [235, 261-262]	500	13	30-40	88.00	18.00	39.00	18.50	19.00

5.3.3 Biodiesel conversion data collection

The third stage of energy life-cycle assessment is the conversion of vegetable oil into the biodiesel. The several processes such as direct use or blends, micro-emulsion, pyrolysis and trans-esterification are used for producing the biodiesel from vegetable oils or animal fats [213]. Among the above technique, trans-esterification is the universal processes adopted for the production of biodiesel. For the conversion of biodiesel, the two steps esterification and transesterification conducted simultaneously. The esterification is also

known as the pre-treatment of oil with methanol (30% v/v of oil) and acid catalyst- H_2SO_4 (1% v/v of oil) at $65^\circ C$ for 1.5-2.0 hour to reduced its free fatty acid. The pre-treatment of oil conducted to avoid the soap formation during the transesterification process and hence ultimately it leads to increase the biodiesel yield.

The trans-esterification process is carried out at $65^\circ C$ temperature for 2 hours (h) with methanol (as alcohol, 30% v/v of oil) in the presence of base catalyst-NaOH or KOH (0.5-1% wt/v of oil) [213, 239]. Both processes have conducted on transesterification unit, which is installed in CERD lab of IIT (BHU) Varanasi. The capacity of the transesterification unit is 50 litres per batch production of biodiesel. It contains four stage of power consuming unit (table 5.4) and corresponding electricity consumed in biodiesel production is as follows:-

Table 5.4: Power consumption in transesterification unit

	Use and time of operation	Power	Power consumed
Motor 1	Mixing of catalyst and alcohol for half an hour	0.37 kW	$0.37 \text{ kW} \times 0.5 \text{ h} = 0.185 \text{ kWh}$
Motor 2	Water circulate in condenser for 2 hours	0.75 kW	$0.75 \text{ kW} \times 2 \text{ h} = 1.5 \text{ kWh}$
Motor 3	Mixture transfer from reactor to washing tank	0.75 kW	$0.75 \text{ kW} \times (1/60) \text{ h} = 0.0125 \text{ kWh}$
Heater	Heating of mixture in reactor for 2 hours	2.9 kW	$2.9 \text{ kW} \times 2 \text{ h} = 5.8 \text{ kWh}$
			Total= 7.49 kWh

The total time for single batch biodiesel production:-

$$= \text{Esterification Time} + \text{Transesterification Time}$$

$$= 2 \text{ hr} + 2 \text{ hr} = 4 \text{ hr}$$

Electricity consumption in per batch biodiesel production = $7.49 \text{ kWh} \times 2 = 14.98 \text{ kWh}$

Number of batch = Total quantity of oil / 50

(Note: Number of batch must be integer)

Total time = Number of batch \times 4 hr

Total electricity used = $14.98 \text{ kWh} \times$ Total time

5.4 Requirement of men and materials:

There are several activities such as preparation of the site, digging of pits, planting and replanting, fertilizer and pesticides application, weeding and soil working, harvesting, etc. are conducted during the cultivation of the crop. The requirement of men and material for these activities for selected vegetable oil including; Jatropha, Mahua, Neem, Palm, Coconut, Karanja, Jojoba, and Tung are discussed below. The oil and seed cake obtained from harvested seeds of these plants. The required chemicals such as methanol, NaOH, and H_2SO_4 in production of biodiesel from the selected vegetable oil are also calculated.

5.4.1 Jatropha

(a) Cultivation [78, 230]

- Botanical name: Jatropha curcas
- Number of plants/ha: 2500
- Poly bag: 2500 and 500 during 1st year and 2nd year.
- Gestation period: 1-2 Years
- Spacing between pits: $2\text{m} \times 2\text{m}$, size of pits: 30 cm^3
- Preparation of site i.e. cleaning and levelling: 10 MD (man day)

- Alignment and stacking: 5 MD
- Digging of pits (@ 50 pits/MD): 25 and 25 MD during 1st and 2nd year.
- Farm yard manure (FYM) requirement : 2 kg per pits during 1st year
: 1 kg per pits during 2nd year
- Fertilizer requirements : 50 gram per plant during 1st year
: 25 gram per plant during 2nd year
- Plants protections: Pesticides application @ 2.6 kg/ha
- Mixing of FYM, insecticides, fertilizers and refilling of pits (@ 100 pits/MD)
: 50 MD (during 1st and 2nd year)
- Planting and replanting (@100 plants/MD): 25 MD during 1st year
: 5 MD during 2nd year
- Irrigations (@15 litre water/plant/irrigation): 3 irrigations during 1st year
: 2 irrigations during 2nd year
- Diesel required for irrigation and for weeding and soil working:
- 27 litre/ha during 1st year
- 17 litre/ha during 2nd year
- Weeding and soil working: 40 MD during 1st and 2nd year
- Harvesting: 2 MD per 100 kg of seed
- Average seed yield (kg/ha/year):

Year	1 st	2 nd	3 rd	4 th	5 th	6 th & onwards
kg/ha/year	Gestation period	300	600	1500	2000	4000

(b) Oil Extraction [204,249]

- After the decortications weight of the seeds has become the 60% of the original weight of seeds, i.e. weight of seed= 0.6 × original weight of seed (with kernel)

- Oil content in seed = $0.38 \times \text{weight of seed}$
- Seed cake = $0.62 \times \text{weight of seed}$

(c) Biodiesel Production [97]

- Process: Two step esterification and trans-esterification
- Methanol = $0.30 \times \text{weight of oil}$ (for Esterification)
 $= 0.30 \times \text{weight of oil}$ (for Trans-esterification)
- Sodium hydroxide (NaOH) = $0.01 \times \text{weight of oil}$
- Sulphuric Acid (H₂SO₄) = $0.01 \times \text{weight of oil}$
- Produced Biodiesel = $0.97 \times \text{weight of oil}$
- Produced Glycerine = $0.18 \times \text{weight of oil}$

5.4.2 Mahua

(a) Cultivation [79, 231]

- Botanical name: Madhuca longifolia
- Number of plants/ha: 200
- Poly bag: 200 and 60 during 1st and 2nd year.
- Gestation period: 8 Years
- Spacing between pits: 7m \times 7m
- Site preparation i.e. cleaning and levelling: 5 MD
- Alignment and stacking: 2 MD
- Digging of pits: 10 MD
- FYM requirement : 10 kg per pit during 1st year
: 5 kg per pit from 2nd to 8th year

- Fertilizer requirements : 225 gram per plant during 1st year
: 112.5 gram per plant from 2nd to 8th year
- Plants protections (Pesticides application @):
 - 1.73 kg/ha/y from 1st to 4th year
 - 4.32 kg/ha/year from 5th to 8th year
 - 6.92 kg/ha/year from 9th year onwards
- Mixing of FYM, insecticides fertilizers and refilling of pits(@100 pits/MD): 2 MD
- Planting and replanting (@50 plants/MD): 4 MD and 1 MD during 1st and 2nd year
- Water required for irrigations: 37500 litre/ha during 1st and 2nd year
: 25000 litre/ha from 3rd to 8th year
- Diesel required for irrigation and for weeding and soil working:
 - 19.8 litre/ha during 1st and 2nd year
 - 14.8 litre/ha from 3rd to 8th year
- Weeding and soil working: 8 MD/ha/year from 1st to 8th year.
- Harvesting: 1 MD per 100 kg of seed
- Average seed yield (kg/ha/year):

Year	1 st to 8 th	9 th	10 th	11 th	12 th	13 th	14 th & onwards
kg/ha/y	G. period	600	1000	1800	3000	3600	5985

(b) Oil Extraction [79, 250]

- The kernels are 70 % of seed by weight. i.e. weight of seed = $0.7 \times$ original weight of seed (with kernel)
- Oil content in seed = $0.35 \times$ weight of seed
- Seek cake= $0.65 \times$ weight of seed

(c) Biodiesel Production [128]

- Process: Two step esterification and trans-esterification
- Methanol = $0.30 \times$ weight of oil (for Esterification)
 $= 0.25 \times$ weight of oil (for Trans-esterification)
- Potassium hydroxide (KOH) = $0.007 \times$ weight of oil
- Sulphuric Acid (H_2SO_4) = $0.01 \times$ weight of oil
- Produced Biodiesel = $0.98 \times$ weight of oil
- Produced Glycerine = $0.18 \times$ weight of oil

5.4.3 Neem

(a) Cultivation [80, 232]

- Botanical name: Azadirachta indica
- Number of plants/ha: 400
- Poly bag: 400 and 80 during 1st and 2nd year.
- Gestation period: 5 Years
- Spacing between pits: $5m \times 5m$
- Preparation of site i.e. cleaning and levelling: 10 MD
- Alignment and stacking: 2 MD
- Digging of pits: 10 MD
- FYM requirement : 10 kg per pit during 1st year
: 2 kg per pit from 2nd to 5th year
- Fertilizer requirements : 500 gram per plant during 1st year
: 250 gram per plant from 2nd to 5th year

- Mixing of FYM, insecticides fertilizers and refilling of pits(@ 40 pits/MD): 10 MD
- Planting and replanting (@100 plants/MD): 4 MD and 1 MD during 1st and 2nd year
- Water required for irrigations: 37500 litre/ha/year during 1st year
: 25000 litre/ha/year from 2nd to 5th year
- Diesel required for irrigation and for weeding and soil working:
 - 19.8 litre/ha/year during 1st year
 - 14.8 litre/ha/year from 2nd to 5th year
- Weeding and soil working: 8 MD/ha/year from 1st to 5th year.
- Harvesting: 2 MD per 100 kg of seed
- Average seed yield (kg/ha/year):

Year	1 st to 5 th	6 th	7 th	8 th	9 th	10 th	11 th	12 th	13 th & onwards
kg/ha/y	G. period	600	1252	1876	3124	5250	7653.6	9240	14628

(b) Oil Extraction [80, 251]

- The seed kernels are 60 % of seed by weight. i.e. weight of seed = $0.6 \times$ original weight of seed (with kernel)
- Oil content in seed = $0.25 \times$ weight of seed
- Seek cake= $0.75 \times$ weight of seed

(c) Biodiesel Production [254, 255]

- Process: Two step esterification and trans-esterification
- Methanol = $0.25 \times$ weight of oil (for Esterification)
- = $0.25 \times$ weight of oil (for Trans-esterification)

- Sodium hydroxide (NaOH) = $0.005 \times$ weight of oil
- Sulphuric Acid (H₂SO₄) = $0.01 \times$ weight of oil
- Produced Biodiesel = $0.95 \times$ weight of oil
- Produced Glycerine = $0.185 \times$ weight of oil

5.4.4 Palm

(a) Cultivation [237, 238]

- Number of plants/ha: 143
- Gestation period: 3 Years
- Spacing (m) - Triangular system: 9m \times 9m \times 9m
- Labour requirement (man days) : 50 MD during 1st year
: 25 MD from 2nd to 4th year

(Manure and fertilizer application, pesticide application, irrigation and interculture operations)

- Manure and fertilizer application (kg/palm/year):-

Year	FYM	Urea	SSP	MOP	MgSO ₄	Borax
1 st	50	0.87	1.25	0.67	0.125	0.025
2 nd	50	1.74	2.50	1.33	0.25	0.05
3 rd & above	50	2.61	3.75	2.00	0.5	0.1

- Drip irrigations (water required):
 - 160 litre/palm/day from 1st to 4th year
 - 200 litre/palm/day for 8 month in a year from 5th year and onwards
- Diesel required : 494.42 litre during 1st year
: 6.67 litre during 2nd year and onwards
- Watch and ward : 13 MD from 3rd year and onwards

- Average yield (ton/ha/year) :-

Year	1 st to 3 rd	4 th	5 th	6 th	7 th	8 th	9 th	10 th & onwards
ton/ha/year	Gestation period	4	6	8	12	14	16	18

(b) Oil Extraction [256, 257]

- Fibres and shell = 190 kg/ton of FFB
- Empty fruit bunches (EFB) = 230 kg/ton of FFB
- Palm oil mill effluent (POME) = 600-700 kg/ton of FFB
- Palm kernel = 0.3 ton/ton crude palm oil (CPO)
- 20 % oil is obtained from one ton of Fresh Fruit Bunch (FFB)
- Oil content = $0.2 \times \text{weight FFB}$
- Oil cake = $0.133 \times \text{weight FFB}$

(c) Biodiesel Production [198]

- Process: Two step esterification and trans-esterification
- Methanol = $0.25 \times \text{weight of oil}$ (for Esterification)
- $= 0.25 \times \text{weight of oil}$ (for Trans-esterification)
- Sodium hydroxide (NaOH) = $0.005 \times \text{weight of oil}$
- Sulphuric Acid (H₂SO₄) = $0.005 \times \text{weight of oil}$
- Produced Biodiesel = $0.92 \times \text{weight of oil}$
- Produced Glycerine = $0.11 \times \text{weight of oil}$

5.4.5 Coconut

(a) Cultivation [236, 253]

- Number of plants/ha : 177

- Gestation period : 6 Years
- Spacing (m) : 7.5m×7.5m
- Labour requirement : 101 MD during 1st year

: 42 MD from 2nd to 7th year

(Digging, filling and planting, manure and fertilizer application pesticide application Irrigation and interculture operations)

- Manure and fertilizer application (kg/plant/year):

Year	FYM	N as Urea	P as Rock Phosphate	K as Murate of Potash
1 st	40	0.11	0.25	0.23
2 nd	20	0.36	0.75	0.67
3 rd	25	0.73	1.50	1.35
4 th & above	30	1.11	2.00	2.00

- Water required (for 3 month of year): 200 litre/plant/day from 1st year and onwards
- Diesel required : 494.42 litre during 1st year
: 6.67 litre during 2nd year and onwards
- Collection and handling: 7, 13, 20, 30, and 39 MD from 7th to 11th year and onwards
- Harvesting : 442.5 nut/MD
- Average nut yield (no./ha) :

Year	1 st to 6 th	7 th	8 th	9 th	10 th	11 th & onwards
nut/ha/year	Gestation period	1770	3540	5310	7965	10620

(b) Oil Extraction [252]

- Oil contents (14.89 % of nut) = 0.1489 × number of nuts

: 2 kg per pit from 2nd to 4th year

- Fertilizer requirements : 500 gram per plant during 1st year
: 250 gram per plant from 2nd to 4th year
- Mixing of FYM, insecticides fertilizers and refilling of pits (@ 40 pits/MD):- 19.5 MD
- Planting and replanting (@100 plants/MD) :- 5 MD and 1 MD during 1st and 2nd year
- Irrigations : Three irrigations during 1st and 2nd year (37500 litre/ha/year)
: One irrigation during 3rd and 4th year (12500 litre/ha/year)
- Diesel required for irrigation and for weeding and soil working :
- 19.8 litre/ha/year during 1st and 2nd year
- 10 litre/ha/year during 3rd to 4th year
- Weeding and soil working : 8 MD/ha/year from 1st to 4th year
- Plants protections (Pesticides application @) : 1.73 kg/ha/year during 1st year
: 3.70 kg/ha/year from 2nd to 4th year
- Harvesting :- 2 MD per 100 kg of seed
- Average seed yield (kg/ha/year) :

Year	1 st to 4 th	5 th	6 th	7 th	8 th	9 th	10 th	11 th & onwards
kg/ha/y	G. period	2000	3000	4000	5000	7000	8000	9000

(b) Oil Extraction [81]

- The seed kernels are 60 % of seed by weight. i.e. weight of seed = 0.6 × original weight of seed (with kernel)
- Oil content in seed = 0.275 × weight of seed
- Seek cake= 0.725 × weight of seed

(c) Biodiesel Production [259]

- Process: Two step esterification and trans-esterification
- Methanol = $0.33 \times \text{weight of oil}$ (for Esterification)
 $= 0.33 \times \text{weight of oil}$ (for Trans-esterification)
- Sodium hydroxide (NaOH) = $0.01 \times \text{weight of oil}$
- Sulphuric Acid (H₂SO₄) = $0.005 \times \text{weight of oil}$
- Produced Biodiesel = $0.98 \times \text{weight of oil}$
- Produced Glycerine = $0.20 \times \text{weight of oil}$

5.4.7 Jojoba

(a) Cultivation [233]

- Botanical name: Simmondsia chinensis
- Number of plants/ha: 2500 (2250 Female, 250 Male)
- Poly bag: 2500 and 500 during 1st and 2nd year respectively.
- Gestation period: 4 Years
- Spacing between pits: 2m × 2m
- Preparation of site i.e. cleaning and levelling: 10 MD
- Alignment and stacking: 5 MD
- Digging of pits: 50 MD
- FYM requirement : 3 kg per pit during 1st year
: 1 kg per pit from 2nd to 4th year
- Fertilizer requirements (kg/ha):

Year	N ₂ O	P ₂ O ₅	K ₂ O
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1 st	75	37.5	75
2 nd to 4 th year	90	45	90

- Mixing of FYM, insecticides fertilizers and refilling of pits(@ 40 pits/MD): 25 MD
- Planting and replanting (@100 plants/MD): 50 MD during 1st year
: 10 MD during 2nd year
- Water required for irrigations: 37500 litre/ha/year from 1st to 4th year
- Diesel required for irrigation, weeding and soil working:
 - 27 litre/ha/year during 1st year
 - 17 litre/ha/year from 2nd to 4th year
- Weeding and soil working: 16 MD/ha/year from 1st to 4th year
- Plants protections (Pesticides application @): 6.5 kg/ha/year during 1st year
: 4.3 kg/ha/year from 2nd to 10th year
- Harvesting: 1 MD per 25 kg of seed
- Average seed yield (kg/ha/year):

Year	1 st to 4 th	5 th	6 th	7 th	8 th	9 th	10 th	11 th	12 th	13 th & onwards
kg/ha/y	G. period	135	248	383	540	743	1440	1701	2432	3375

(b) Oil Extraction [233]

- Jojoba whole fruit comprising of 36 % hull and 64% seed containing about 50 % oil in it.
- Oil content in seed = 0.50 × weight of seed
- Seek cake= 0.50 × weight of seed

(c) Biodiesel Production [260]

- Process: Two step esterification and trans-esterification
- Methanol = $0.30 \times \text{weight of oil}$ (for Esterification)
 $= 0.30 \times \text{weight of oil}$ (for Trans-esterification)
- Sodium hydroxide (NaOH) = $0.01 \times \text{weight of oil}$
- Sulphuric Acid (H₂SO₄) = $0.01 \times \text{weight of oil}$
- Produced Biodiesel = $0.97 \times \text{weight of oil}$
- Produced Glycerine = $0.18 \times \text{weight of oil}$

5.4.8 Tung

(a) Cultivation [235]

- Botanical name: Aleurites fordii
- Number of plants/ha: 500
- Poly bag: 500 and 50 during 1st and 2nd year.
- Gestation period: 4 Years
- Spacing between pits: 5m × 4m
- Preparation of site i.e. cleaning and levelling: 10 MD
- Alignment and stacking: 2 MD
- Digging of pits: 12.5 MD
- FYM requirement: 10 kg per pit during 1st year
: 2 kg per pit from 2nd to 4th year
- Fertilizer requirements : 500 gram per plant during 1st year
: 250 gram per plant from 2nd to 4th year

- Mixing of FYM, insecticides fertilizers and refilling of pits (@ 40 pits/MD): 19.5 MD
- Planting and replanting (@100 plants/MD): 5 MD and 2 MD during 1st and 2nd year
- Water required for irrigations: 37500 litre/ha/year during 1st year
: 25000 litre/ha/year from 2nd to 4th year
- Diesel required for irrigation and for weeding and soil working:
 - 19.8 litre/ha/year during 1st year
 - 14.8 litre/ha/year from 2nd to 4th year
- Weeding and soil working: 8 MD/ha/year from 1st to 4th year
- Plants protections (Pesticides application @): 4.3 kg/ha/year from 1st to 4th year
- Harvesting: 1 MD per 100 kg of seed
- Average seed yield (kg/ha/year):

Year	1 st to 4 th	5 th	6 th	7 th	8 th	9 th	10 th	11 th	12 th	13 th & onwards
kg/ha/y	G. period	500	750	1125	1500	2000	2375	2875	3375	3625

(b) Oil Extraction [234]

- Jojoba whole fruit comprising of 36 % hull and 64% seed containing about 50 % oil in it.
- Oil content in seed = 0.30 × weight of seed
- Seed cake = 0.70 × weight of seed

(c) Biodiesel Production [261]

- Process: Two step esterification and trans-esterification

- Methanol = $0.30 \times \text{weight of oil}$ (for Esterification)
 = $0.30 \times \text{weight of oil}$ (for Trans-esterification)
- Sodium hydroxide (NaOH) = $0.01 \times \text{weight of oil}$
- Sulphuric Acid (H₂SO₄) = $0.01 \times \text{weight of oil}$
- Produced Biodiesel = $0.8888 \times \text{weight of oil}$
- Produced Glycerine = $0.18 \times \text{weight of oil}$

5.5 Energy analysis

This analysis conducted by using the energy equivalent coefficient (Table 5.1) of several inputs such as human labor, machinery, fertilizer, chemical, etc., and requirement of men and materials (section 5.4) for three stages; cultivation, oil extraction, and biodiesel production from selected vegetable oil plants (Jatropha, Mahua, Neem, Palm, Coconut, Karanja, Jojoba and Tung) for 20 years. The analysis includes the recovery and reuse of chemicals used during the production of biodiesel. In this analysis finally calculate the different energy indicators such as energy ratios, net energy, energy productivity, energy intensiveness, energy ratio cost, etc. to compare the most energy-efficient vegetable oil plants in the production of biodiesel. The estimation of energy inputs and outputs and its analyses are discussed below:

5.5.1 Calculation of energy input and output

Based on given the men and material in section 5.4 and coefficient of energy equivalent (Table 5.1) calculation of the energy inputs and outputs during the cultivation, oil extraction and biodiesel production from selected vegetable oil plants are followed as:-

(a) Cultivation

- Man power = Total MD/year \times Energy equivalent of human labour (1.96 MJ/hr) \times Working hour in a day (8.0 hr)
- Ploy bag = Poly bag usage/year \times Energy equivalent of ploy bag (0.69 MJ)
- Farmyard manure (FYM) = Total required FYM (kg/ha/year) \times Energy equivalent of FYM (0.3 MJ/kg)
- Fertilizers: Required quantities are follow as:-
 - Nitrogen (kg/ha/year) \times Energy equivalent of Nitrogen (66.14 MJ/kg)
 - Phosphate (kg/ha/year) \times Energy equivalent of Phosphate (12.14 MJ/kg)
 - Potassium (kg/ha/year) \times Energy equivalent of Potassium (11.15 MJ/kg)
 - Sulphur (kg/ha/year) \times Energy equivalent of Sulphur (1.12 MJ/kg)
- Deisel = Total required diesel (L/ha/year) \times Energy equivalent of diesel (47.8 MJ/L)
- Water = Total required water for irrigation (litre/ha/year) $\times 10^{-3} \text{ m}^3 \times$ Energy equivalent of water (1.02 MJ/m³)
- Pesticides = Total pesticide applied (kg/ha/year) \times Energy equivalent of herbicides/inceticides (MJ/kg)

(b) Oil Extraction

- Electricity: Total electricity consumed in three different unit
 - Decorticator = $\frac{\text{Total seed yield } (\frac{\text{kg}}{\text{ha}}/\text{year})}{\text{Decorticator capacity } (150 \text{ kg/hr})} \times \text{Decorticator power } (1.5 \text{ kW})$
 - Expeller = $\frac{\text{Total decorticated seed } (\frac{\text{kg}}{\text{ha}}/\text{year})}{\text{Expeller capacity } (50 \text{ kg/hr})} \times \text{Expeller power } (5.5 \text{ kW})$
 - Filter = $\frac{\text{Total expelled seed } (\frac{\text{kg}}{\text{ha}}/\text{year})}{\text{Filter press capacity } (600 \text{ kg/hr})} \times \text{Filter power } (1.5 \text{ kW})$

Total energy consumed = Electricity consumed in Decorticator + Expeller + Filter (kWh) × Energy equivalent of electricity (11.93 MJ/kWh)

- Man power = Total MD/year × Energy equivalent of human labour (1.96 MJ/hr) × Working hour in a day (8.0 hr)

By-product

Seed/oil cake = Total produced seed cake (kg/ha/year) × Energy equivalent of oil/seed cake (MJ/kg)

(c) Biodiesel Production

The consumption of electricity (subsection 5.3.3) and requirement of chemical (section 5.4) during the biodiesel production on the transesterification unit from different feedstocks including; Jatropha, Mahua, Neem, Palm, Coconut, Karanja, Jojoba, and Tung are discussed already in this chapter. Thus, the following equations have been used to calculate the expenses of energies in the production of biodiesel.

- Methanol = Total methanol used (kg/ha/year) × Energy equivalent of methanol (33.67 MJ/kg)
- KOH = Total KOH used (kg/ha/year) × Energy equivalent of KOH (19.87 MJ/kg)
- NaOH = Total NaOH used (kg/ha/year) × Energy equivalent of NaOH (23.30 MJ/kg)
- HCl = Total HCl used (kg/ha/year) × Energy equivalent of HCl (21 MJ/kg)
- H₂SO₄ = Total H₂SO₄ used (kg/ha/year) × Energy equivalent of H₂SO₄ (3 MJ/kg)
- Electricity = Total electricity used (kWh/ha/year) × Energy equivalent of electricity (11.93 MJ/kWh)

- Man power = Total MD/year \times Energy equivalent of human labour (1.96 MJ/hr) \times Working hour in a day (8.0 hr)

Product

Biodiesel = Total produced biodiesel (kg/ha/year) \times Energy equivalent of biodiesel (MJ/kg)

By-product

Glycerine = Total produced glycerine (kg/ha/year) \times Energy equivalent of biodiesel (MJ/kg)

5.5.2 Energy input and output analysis

Table 5.5 shows the total input and output energy of different biodiesel plants. It was estimated with the help of above equations (given in subsection 5.5.1) and above data (section 5.4) during the cultivation, oil extraction, and biodiesel production of Jatropha, Mahua, Neem, Palm, Coconut, Karanja, Jojoba and Tung for 20 years. The duration from seedling to starts of fruiting is known as the gestation period of the plants. In this period, generally lower energy input required for all plants except coconut and palm and after that its value reaches the maximum at maturity of plants. During the gestation period, higher energy input for coconut and palm due to the requirement of materials such as fertilizer, chemical, and water is increases. All the plants start the fruiting after completion of its gestation period. After that period, the material inputs (fertilizers, chemicals, etc.) are stopped or reduced for all plants, that is why lower energy inputs. The seed/fruit yields are increases when the plants completed its gestation periods and reach maximum at maturity. At the same time, oil extraction and biodiesel production are also started. For the production of biodiesel needed the chemical such as alcohol (methanol),

acid (H_2SO_4) and base catalyst (NaOH/KOH) and hence increases energy inputs. Initially, during the cultivation of crop (seedling to gestation) there is no output. All the plants are started fruiting after the completion of the gestation period its value increases up to its maturity. Therefore energy output also increases and achieved maximum at maturity of plants.

There are several by-products such as wood, fruit kernel, tree leaves, seed cake, glycerine etc. are obtained during the energy life cycle assessment of biodiesel plants. Amongst these by-products seed/oil cake (during oil extraction) and glycerine (by product of biodiesel) are considered as output. The figure 5.1 shows the total energy output increases, when by-product seed cake and glycerine considered as output.

5.5.3 Energy input/output after maturity of plants

Figure 5.1 shows the energy input and output after maturity of plants for Jatropha, Mahua, Neem, Palm, Coconut, Karanja, Jojoba, and Tung. Energy inputs for these plants are 26313.29, 56837.18, 96726.06, 88518.31, 51903.65, 79753.43, 38926.68 and 32043.27 MJ/ha, and the energy outputs are 32970.53, 76126.96, 137576.3, 100399.8, 59309.89, 91180.48, 54373.76 and 37696.23 MJ/ha respectively while only biodiesel considered as output.

The energy output for these plants is increased by 12.75%, 9.18%, 7.38%, 6.33%, 5.67%, 10.04%, 10.33% and 9.61% when the main product biodiesel and co-product glycerine both consider as output. Similarly, with addition of both co-products glycerine and seed cake, the energy output increased by 112.03%, 111.46%, 158.32%, 44.76%, 40.55%, 112.38%, 78.12% and 137.50%.

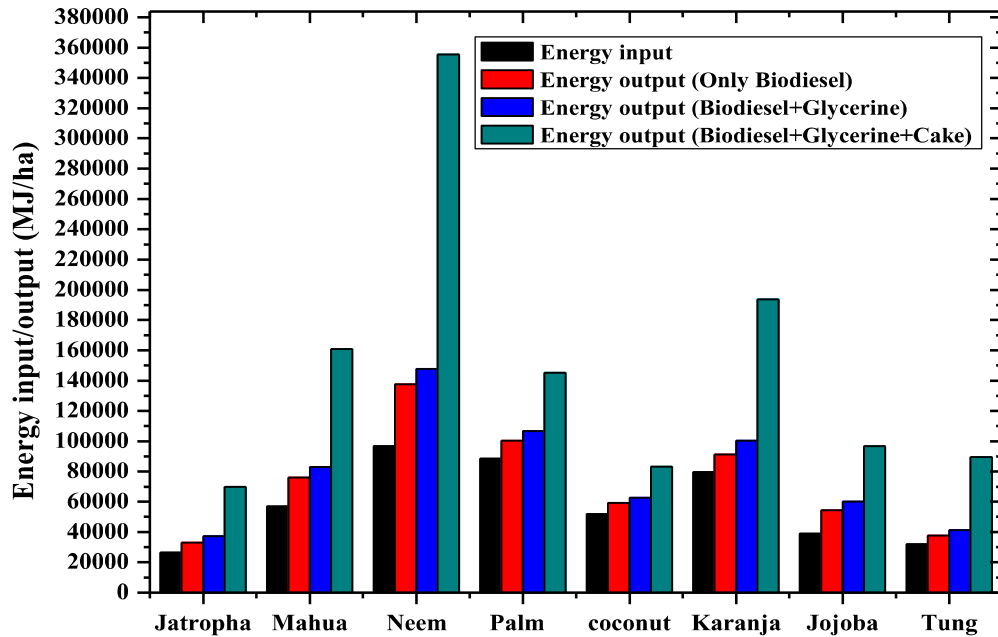


Figure 5.1: Energy input/output after maturity of plants

5.5.4 Energy input analysis with methanol recovery

The esterification and trans-esterification process have been conducted for biodiesel production. These processes have been done by using the methanol as alcohol in the presence of acid and base catalyst H_2SO_4 and $NaOH/KOH$. From these inputs, methanol contributed higher energy input during the life assessment of biodiesel plants. Therefore, its (methanol) recovery is necessary to minimize the net energy input during the esterification and trans-esterification process. It was estimated during the experiment in the lab that 50%, 52.70%, 55.81%, 52.27%, and 52.67% methanol recovery for Castor, Mahua, Neem, Coconut, and Linseed oil while producing the biodiesel on transesterification unit. On that basis for the energy calculations, it was taken average value 52.69% methanol recovery of the above results to the remaining oil (Jatropha,

Palm, Karanja, Jojoba, and Tung). The recovered methanol is reused for further conducting esterification and trans-esterification processes, and therefore

$$\text{Net energy input} = \text{Total energy input} \times (1 - \% \text{Methanol recovery})$$

With used of above equation calculate the net energy input after recovery and reused of methanol during the biodiesel production. Figure 5.2 shows the energy input with methanol recovery during the biodiesel production for all the vegetable oil plants for 20 years. After the gestation period of the plants, it starts yielding and methanol used during the biodiesel production and recovery of methanol is considered. Therefore, the net energy input decreases (figure 5.2) for all the biodiesel plants in comparison to without methanol recovery after gestation period of plants. Thus, net energy inputs are decreased by 36.89%, 36.04%, 35.52%, 32.07%, 40.23%, 36.34%, 38.45% and 36.13% respectively for Jatropha, Mahua, Neem, Palm, Coconut, Karanja, Jojoba and Tung (figure 5.3).

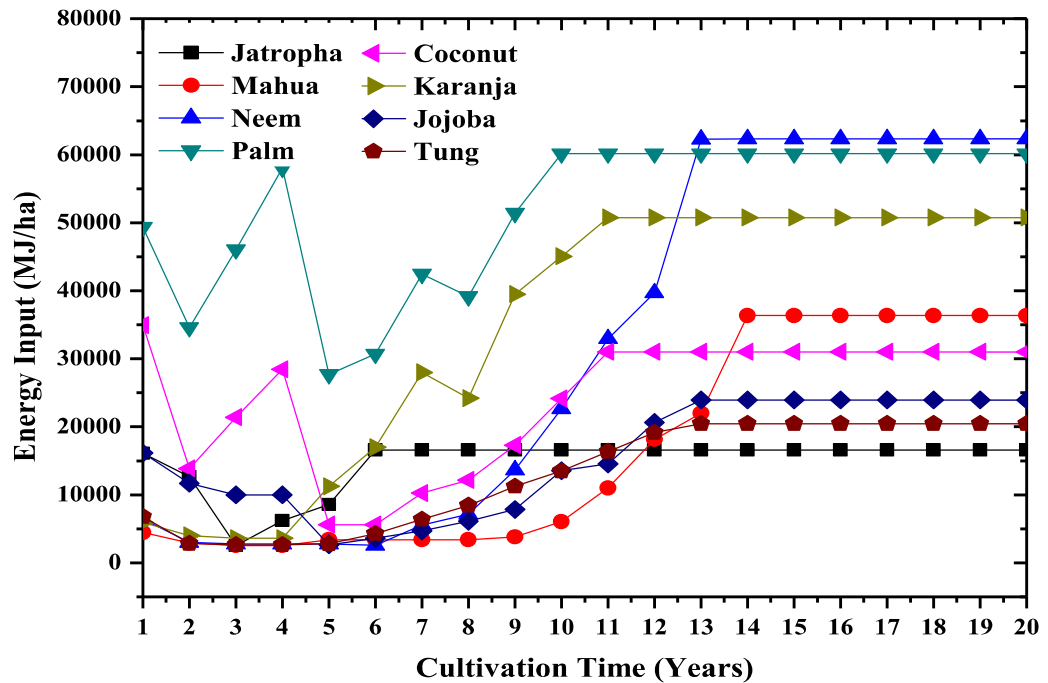


Figure 5.2: Energy input with methanol recovery

Table 5.5: Energy input and output of different biodiesel plants for 20 year

Years	Jatropha		Mahua		Neem		Palm		Coconut		Karanja		Jojoba		Tung	
	Input (MJ/ha)	Output (MJ/ha)	Input (MJ/ha)	Output (MJ/ha)	Input (MJ/ha)	Output (MJ/ha)	Input (MJ/ha)	Output (MJ/ha)	Input (MJ/ha)	Output (MJ/ha)	Input (MJ/ha)	Output (MJ/ha)	Input (MJ/ha)	Output (MJ/ha)	Input (MJ/ha)	Output (MJ/ha)
1	16088.9	0	4442.7	0	6450.0	0	49354.8	0	34953.1	0	5957.2	0	16125.7	0	6776.2	0
2	13356.3	5244.3	2878.5	0	2988.3	0	34603.1	0	13828.9	0	4005.3	0	11689.2	0	2867.6	0
3	4020.5	10486.4	2561.2	0	2760.6	0	46069.9	0	21379.6	0	3619.0	0	9982.8	0	2672.6	0
4	9843.7	26215.9	2561.2	0	2760.6	0	65128.3	38665.7	28450.8	0	3619.0	0	9982.8	0	2672.6	0
5	13405.6	35316.0	3380.2	0	2760.6	0	36559.3	48312.8	5618.7	0	17702.3	43032.3	3362.9	4308.9	4413.3	12349.0
6	26313.3	69909.0	3380.2	0	4014.9	14518.4	41361.4	57998.6	5618.67	0	26648.1	64548.5	4904.2	7899.7	6712.9	18523.5
7	26313.3	69909.0	3380.2	0	8515.1	30293.1	60205.9	96625.7	13732.2	13881	40890.4	47740.7	6716.1	12208.5	9976.5	27785.2
8	26313.3	69909.0	3380.2	0	11559.7	45235.1	58667.0	106328.9	19126.6	27767.5	40307.6	107580.8	8985.1	17238.5	13249.9	37046.9
9	26313.3	69909.0	5844.9	16072.6	20971.1	75587.5	74449.0	125663.6	27752.0	41677.6	62051.1	150613.2	11798.6	23699.0	17653.4	49395.9
10	26313.3	69909.0	9426.4	26837.0	34989.1	127547.4	88518.3	145338.0	39825.9	62516.9	70809.3	172129.3	21218.7	45962.0	21102.8	58657.6
11	26313.3	69909.0	17163.1	48306.6	50908.8	185942.3	88518.3	145338.0	51903.6	83361.3	79753.4	193645.5	23589.4	54292.3	25516.2	71006.6
12	26313.3	69909.0	28402.9	80511.0	61428.5	224483.5	88518.3	145338.0	51903.6	83361.3	79753.4	193645.5	33570.6	77631.8	29929.5	83355.6
13	26313.3	69909.0	34318.4	96613.2	96682.4	355383.6	88518.3	145338.0	51903.6	83361.3	79753.4	193645.5	38926.7	95911.6	32043.3	89530.1
14	26313.3	69909.0	56837.2	160981.7	96682.4	355383.6	88518.3	145338.0	51903.6	83361.3	79753.4	193645.5	38926.7	95911.6	32043.3	89530.1
15	26313.3	69909.0	56837.2	160981.7	96682.4	355383.6	88518.3	145338.0	51903.6	83361.3	79753.4	193645.5	38926.7	95911.6	32043.3	89530.1
16	26313.3	69909.0	56837.2	160981.7	96682.4	355383.6	88518.3	145338.0	51903.6	83361.3	79753.4	193645.5	38926.7	95911.6	32043.3	89530.1
17	26313.3	69909.0	56837.2	160981.7	96682.4	355383.6	88518.3	145338.0	51903.6	83361.3	79753.4	193645.5	38926.7	95911.6	32043.3	89530.1
18	26313.3	69909.0	56837.2	160981.7	96682.4	355383.6	88518.3	145338.0	51903.6	83361.3	79753.4	193645.5	38926.7	95911.6	32043.3	89530.1
19	26313.3	69909.0	56837.2	160981.7	96682.4	355383.6	88518.3	145338.0	51903.6	83361.3	79753.4	193645.5	38926.7	95911.6	32043.3	89530.1
20	26313.3	69909.0	56837.2	160981.7	96682.4	355383.6	88518.3	145338.0	51903.6	83361.3	79753.4	193645.5	38926.7	95911.6	32043.3	89530.1

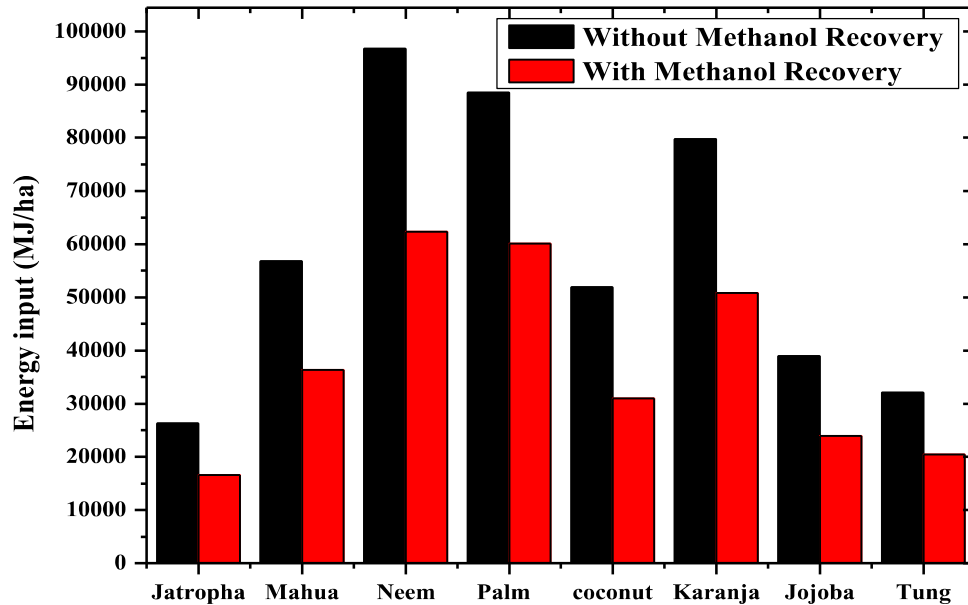


Figure 5.3: Energy input after maturity of plants

5.5.5 Energy analysis of input-output energy used in the biodiesel production

Based on the above energy analysis, calculate the net input and output energy used in the production of biodiesel. The equations for energy expenses (MJ/ha/year) and energy produced (MJ/ha/year) in three phases; cultivation, oil extraction, and biodiesel production are already formulated in section (5.5.1). The estimation of several energy inputs such as manpower, machinery, fertilizer, chemical, etc., in biodiesel production is follows as:-

$$\text{Energy consumed in biodiesel production} = \frac{\text{Total energy input in 20 year (MJ)}}{\text{Total biodiesel produced in 20 year (kg)}}$$

$$\text{Energy produced in biodiesel production} = \frac{\text{Total energy output in 20 year (MJ)}}{\text{Total biodiesel produced in 20 year (kg)}}$$

Thus, estimate the energy input and outputs from cultivation to biodiesel production of Jatropha, Mahua, Neem, Palm, Coconut, Karanja, Jojoba, and Tung vegetable oil plants (Table 5.6) with using the above equations.

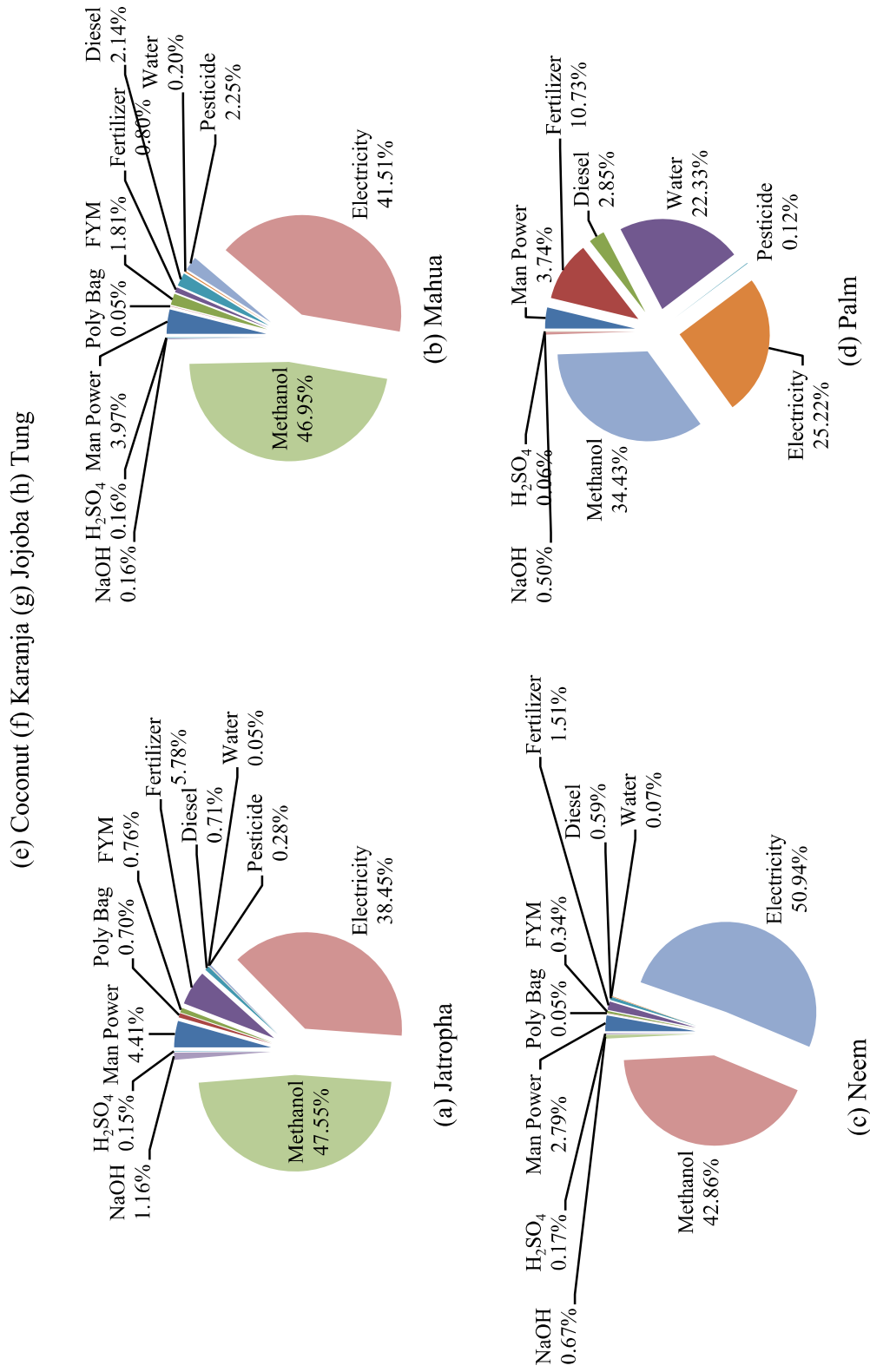
Figure 5.4 shows the energy distribution of the energy used from different inputs in biodiesel production respectively for these plants. The table 5.6 shows total energy consumed for these plants is 20.706, 19.149, 18.548, 27.032, 26.459, 21.736, 21.428, and 22.50 MJ per kg of biodiesel production. It was seen that among all taken plants (except Palm and Coconut), biodiesel production share higher input energy follow by oil extraction and cultivation phase. It may be due to the huge requirement of water palm and coconut oil plants show the higher energy (10.464 and 9.509 MJ/kg of biodiesel) requirement in the cultivation phase as compared to remaining plants.

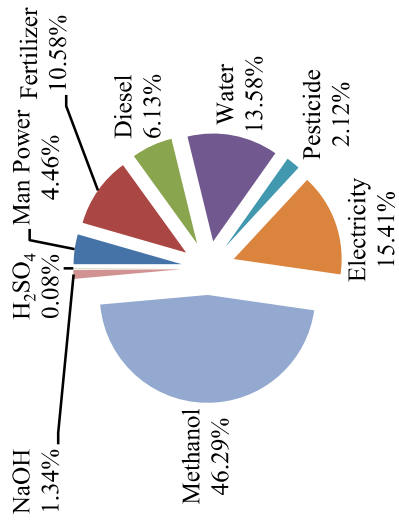
Similarly, in figure 5.4 (a, b, c, d, e, f, g, and h), the biodiesel production phase share higher energy, it is due to the high requirement of methanol during biodiesel production. Lowest energy required for Neem cultivation ($0.77464 \text{ MJ kg}^{-1}$ of biodiesel). It has also been clear from the figure (5.4) that the methanol and electricity share higher energy input in comparison to other remaining. Table 5.5 also shows the total energy output is 78.997, 78.244, 102.320, 53.816, 53.549, 79.453, 69.623, 92.627 MJ/kg of biodiesel respectively for above-selected vegetable oil plants. Among these, Neem shows the highest energy output and on the contrary, the lowest for Coconut and Palm.

Table 5.6: Energy input and output pattern of different biodiesel plants

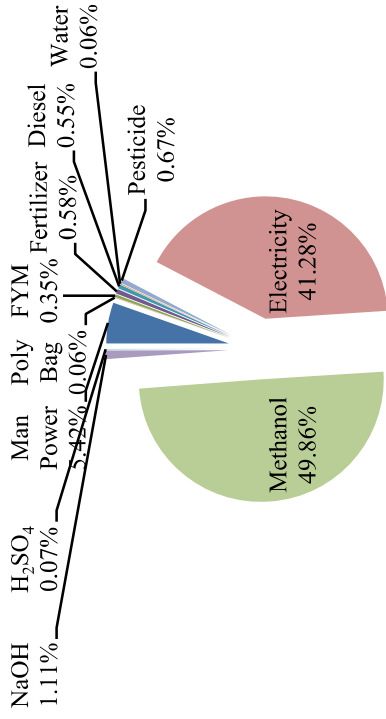
Quantity (Inputs and Outputs)	Total Energy Equivalent (MJ kg ⁻¹)							
	Jatropha	Mahua	Neem	Palm	Coconut	Karanja	Jojoba	Tung
A. Inputs								
1. Cultivation								
a. Man Power	0.573735	0.437734	0.171065	0.723113	0.934112	0.815533	0.555994	0.405154
b. Poly Bag	0.145238	0.009287	0.009555	na	na	0.011955	0.141698	0.041642
c. FYM	0.157868	0.344193	0.062315	na	na	0.075607	0.30804	0.206918
d. Fertilizers	1.195968	0.151417	0.278915	2.901634	2.799554	0.126897	1.968661	0.347289
e. Diesel	0.147568	0.406675	0.108942	0.770976	1.623119	0.119262	0.143971	0.081598
f. Water	0.010735	0.038645	0.012138	6.036369	3.592866	0.01205	0.310859	0.032978
g. Pesticides	0.057464	0.428677	na	0.032365	0.559706	0.146204	0.981107	0.470739
Total cultivation energy (T ₁)	2.288575	1.816628	0.77464	10.46446	9.509357	1.307508	4.130822	1.586319
2. Oil Extraction								
a. Electricity	4.127499	4.204383	5.559323	2.823083	2.276647	5.392606	2.981683	5.402621
b. Man Power	0.170250	0.155725	0.173896	0.105623	0.085336	0.199312	0.111131	0.200541
Total oil extraction energy (T ₂)	4.297749	4.360108	5.733219	2.928706	2.361983	5.591918	3.092814	5.603162
3. Biodiesel Production								
a. Methanol	9.846430	8.938515	7.893916	9.307377	12.24899	10.83848	9.853364	10.75339
b. NaOH	0.240042	0.141935	0.122686	0.13614	0.355184	0.240206	0.240211	0.262153
c. H ₂ SO ₄	0.030907	0.030614	0.031595	0.017529	0.021341	0.015464	0.030928	0.033754
d. Electricity	3.834056	3.699261	3.822484	3.995158	1.801094	3.579154	3.907531	4.082053
e. Man Power	0.168875	0.162498	0.169771	0.183235	0.161593	0.163255	0.172111	0.179798
Total energy biodiesel production energy (T ₃)	14.12031	12.97282	12.04045	13.63944	14.5882	14.83656	14.20415	15.31115
Total input energy (T ₁ +T ₂ +T ₃)	20.70663	19.14956	18.54831	27.0326	26.45954	21.73598	21.42778	22.50063
B. Outputs								
1. Biodiesel	37.270	37.00	39.60	37.20	38.10	37.98	39.862	39.00
2. Glycerol	4.7472	3.398	2.918	2.3202	2.161	3.814	3.8817	3.746
3. Seed/Oil cake	36.979	37.846	59.802	14.296	13.287	37.658	25.879	49.88
Total output energy	78.997	78.244	102.32	53.816	53.549	79.453	69.623	92.627

Figure 5.4: Net energy input distribution for different plants in biodiesel production: (a) Jatropha (b) Mahua (c) Neem (d) Palm

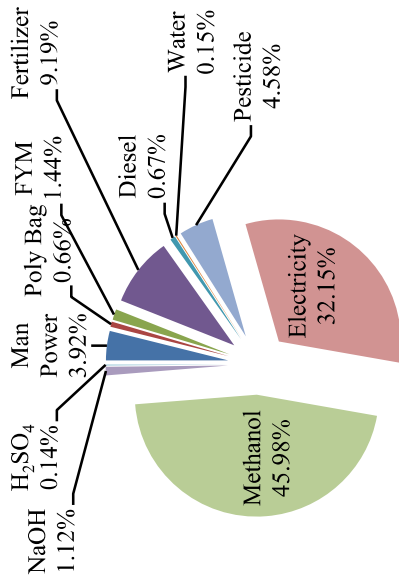




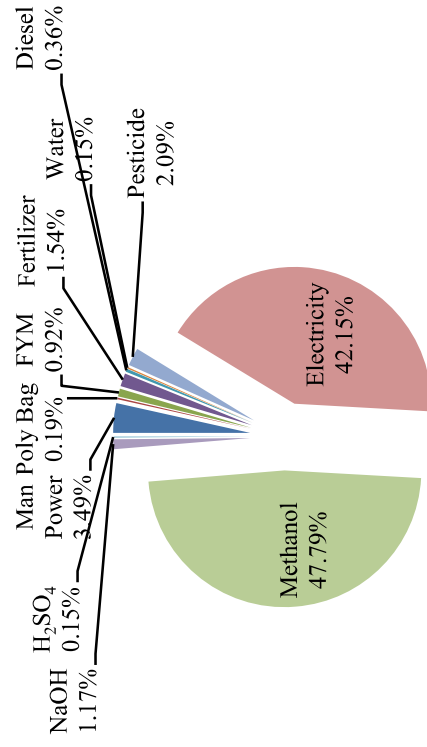
(e) Coconut



(f) Karanja



(g) Jojoba



(h) Tung

5.5.6 Energy indicators

The energy indicators provide a deeper understanding of key problems and discover important relationships that are not evident with basic statistics. These are useful tools for policy makers and the public to communicate energy issues related to sustainable development and to promote institutional dialogue. Each set of energy indicators shows features or importance of energy production and use. Therefore, various energy indicators such as energy ratio (energy use efficiency), specific energy, energy productivity, net energy, fossil energy ratio (FER), energy intensiveness, energy intensity cost, energy intensiveness value and energy ratio cost are calculated on the basis of the energy equivalents of the inputs, output and the surveyed data.

The energy equivalents for different input and output are given in Table 5.1 and 5.3. All the basic information of energy inputs, outputs, and expenses in the production of biodiesel entered into Excel spreadsheets software. The details of important indicators and corresponding expressions for energy analysis were given by Mohammadshirazi et al. [207].

$$\text{Energy use efficiency} = \frac{\text{Output energy (MJ/kg)}}{\text{Input energy (MJ/kg)}} \quad (5.1)$$

$$\text{Energy productivity} = \frac{\text{Biodiesel yield (kg/kg)}}{\text{Input energy (MJ/kg)}} \quad (5.2)$$

$$\text{Net energy} = \text{Output energy} \left(\frac{\text{MJ}}{\text{kg}} \right) - \text{Input energy} \left(\frac{\text{MJ}}{\text{kg}} \right) \quad (5.3)$$

$$\text{Energy intensiveness} = \frac{\text{Input energy (MJ/kg)}}{\text{Total production cost (Rs/kg)}} \quad (5.4)$$

$$\text{Energy intensity cost} = \frac{\text{Total energy cost (Rs/kg)}}{\text{Yield (kg/kg)}} \quad (5.5)$$

$$\text{Energy intensiveness value} = \frac{\text{Input energy (MJ/kg)}}{\text{Gross production value (Rs/kg)}} \quad (5.6)$$

$$\text{Energy ratio cost} = \frac{\text{Total energy cost (Rs/kg)}}{\text{Total production cost (Rs/kg)}} \quad (5.7)$$

$$\text{FER} = \frac{\text{Renewable fuel energy output (MJ/kg)}}{\text{Fossil energy input (MJ/kg)}} \quad (5.8)$$

5.7 Economic analysis

The economic analysis of different vegetable oil plants (Jatropha, Mahua, Neem, Palm, Coconut, Karanja, Jojoba, and Tung) from cultivation to biodiesel production have been done with using the detail of men material requirement (given in section 5.4). The table 5.6 shows economic equivalents of different inputs expenses and output obtained during biodiesel production. These are the following parameters and assumptions considered during the economic analysis:

- Working hour for men are 8 hour in a day
- Input cost is categorized into fixed and variable.
- All machinery and land rant are considered as fixed cost.
- All inputs includes: human labor, fertilizers, electricity, diesel, chemical etc are considered as variable cost.
- All the input cost are varies with current inflation rate (CPI India-2018)
- Human labour charge is categorized into unskilled, semi skilled and skilled.
- Unskilled human labours are used for cultivation of crop and oil extraction from seed.
- Semi skilled human labours used during the biodiesel production.
- Biodiesel setup cost includes both transesterification and oil extraction unit.
- 10 % contingency is considered during estimation of cultivation cost.

- Diesel cost is the average price of diesel six month from January to June 2018.
- During the calculation biodiesel price is fixed throughout the 20 year and equal to average diesel price (53.51 Rs/kg).

5.7.1 Cultivation cost

The plantation of different biodiesel plants depends on geographical location, agricultural condition, input use, other farming practices, etc. The estimation of per hectare cost is related with various stages of different vegetable oil plantations. The economic equivalents of different input are given in table 5.7, which used for estimation of input and output cost at different stage.

- *Plant establishment Cost:* The establishment cost of different vegetable oil plants include cost of nursery practices, seedling, farm yard manure (FYM), human labour on several activities (site preparation, alignment and staking, digging of pits) etc.
- *Operation and Maintenance Cost:* Operation and maintenance cost of different vegetable oil plants include the costs incurred on post plantation management operations. These comprise several operations such as soil working and weeding, FYM and fertilizer application, pruning, application of insecticides and pesticides, etc.
- *Other Associated Costs:* The other associated cost in vegetable oil plantation comprises harvesting, separation of seed, transportation of seed and its marketing. Harvesting and separation of seed from fruits needs human labour as the operations are done manually.

5.7.2 Oil extraction cost

The decortications, seed pressing and oil filtrations processes are carried out simultaneously during the oil extraction. The expenses of these processes are calculated as below.

- Decortications cost = Electricity consumed in decortications (kWh) × Electricity cost (Rs/kWh)
- Expeller cost = Electricity consumed in expel the seed (kWh) × Electricity cost (Rs/kWh)
- Oil filtering cost = Electricity consumed in filter press (kWh) × Electricity cost (Rs/kWh)
- Manpower = Total time consumed in oil extraction (hr) × Wage rate (Rs/hr)

5.7.3 Biodiesel production cost

The transesterification unit has power consuming unit including; aquatic mixing (motor 1), centrifugal pump (circulate the water in condenser: motor 2), centrifugal pump (transfer the trasestrified oil from reactor to washing tank: motor 3), and heater. The electricity consumed in these units has already discussed (section 5.3.3). Manpower, electricity, alcohol (methanol) and catalyst (base-NaOH/KOH and acid-H₂SO₄) are the input expences during the production of biodiesel. The estimation of these expences is discussed below:-

- Man power = Total time consumed in biodiesel production (hr) × Wage rate (Rs/hr)
- Total electricity cost = Total electricity used (kg/kWh) × Electricity cost (Rs/kWh)
- Total methanol cost = Quantity of methanol (kg) × Cost of methanol (Rs/kg)

- Total NaOH/KOH cost = Quantity of NaOH/KOH (kg) × Cost of NaOH/KOH (Rs/kg)
- Total H₂SO₄ cost = Quantity of H₂SO₄ (kg) × Cost of H₂SO₄ (Rs/kg)

Table 5.7: Economic equivalents of inputs and output in biodiesel production [263-267]

Particulars (unit)	Rs/unit	Particulars (unit)	Rs/unit
A. Inputs		B. Outputs	
1. Man power (h)		1. Biodiesel (kg)	53.51
a) Unskilled	31.72	2. Glycerine (L)	25-30
b) Semi skilled	34.89	3. Seed/Oil cake (kg)	13-25
c) Skilled	39.09	a) Jatropha	15.0
2. Diesel (L)	64.31	b) Mahua	13.0
3. Fertilizers (kg)		c) Neem	20.0
a) Nitrogen	5.50	d) Palm	14.0
b) Phosphate	5.00	e) Coconut	25.0
c) Potassium	5.30	f) Karanja	19.0
d) Farm yard manure (FYM)	0.30	g) Jojoba	15.0
4. Electricity (kWh)	10.0	h) Tung	15.0
5. Chemicals (kg)			
a) Methanol	44.84		
b) NaOH	61.36		
c) KOH	94.40		
d) H ₂ SO ₄	21.24		

5.7.4 Economic analysis of biodiesel production

Table 5.8 shows the input cost (expenses) and output cost (incomes) of different biodiesel from cultivation to biodiesel production. It was estimated with using the above equation for cultivation cost (section 5.7.1), oil extraction cost (section 5.7.2), and biodiesel production cost (section 5.7.3). The total input cost comprises variable cost (such as manpower, fertilizers, electricity, chemical for biodiesel production, etc.) and fixed cost (machinery and land rant). The estimation of these expences is following as:-

$$\text{Expences in biodiesel production} = \frac{\text{Total expences (input cost) in 20 year (Rs)}}{\text{Total biodiesel produced in 20 year (kg)}}$$

$$\text{Incomes in biodiesel production} = \frac{\text{Total incomes (output cost) in 20 year (Rs)}}{\text{Total biodiesel produced in 20 year (kg)}}$$

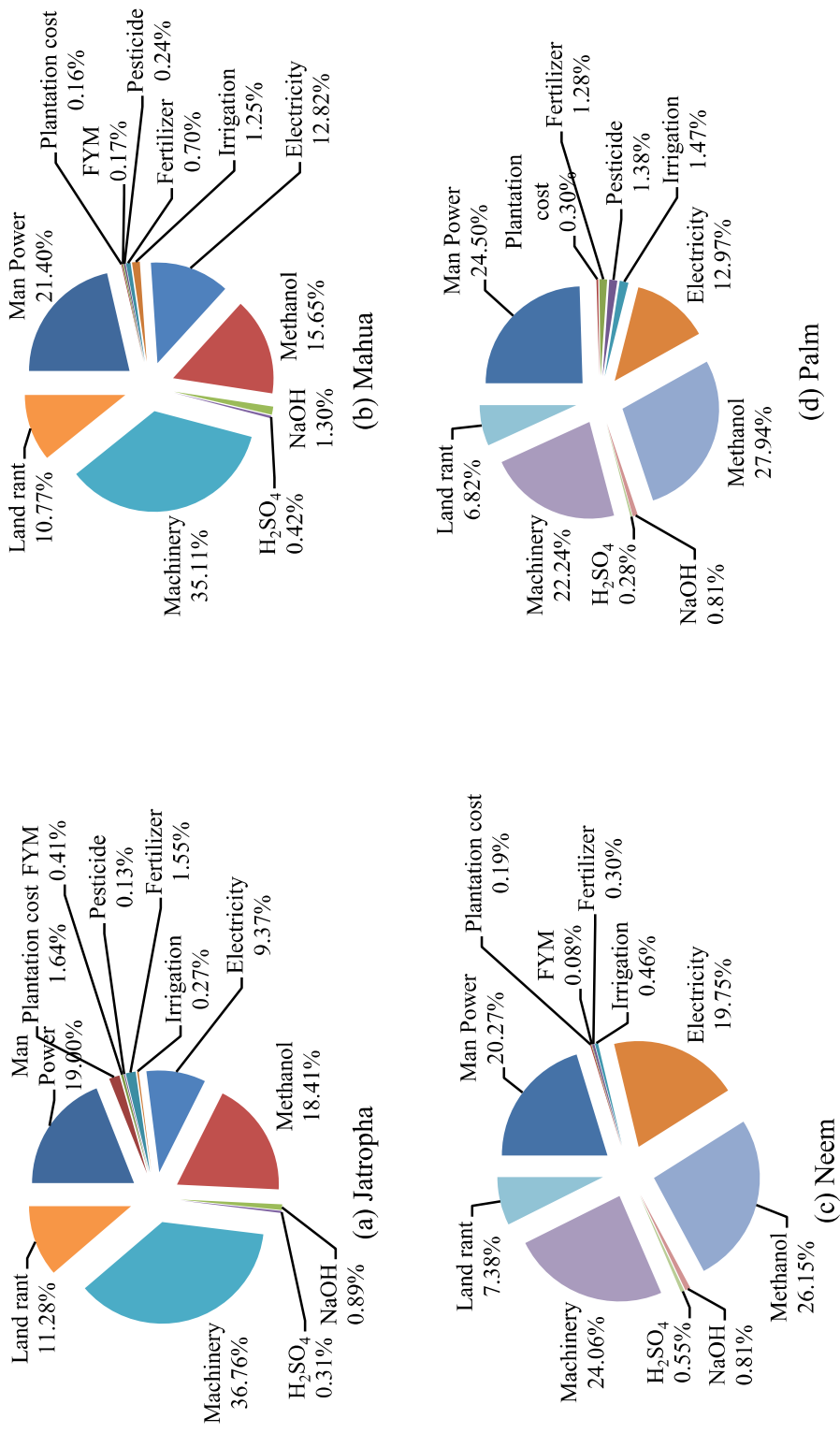
Total expenditure (input cost) are calculated as 124.45, 104.97, 78.14, 76.12, 118.88, 103.29, 103.29, 121.38 and 143.15 Rs kg⁻¹ of biodiesel respectively for Jatropha, Mahua, Neem, Palm, Coconut, Karanja, Jojoba and Tung. Among these values, it can be seen that Palm and Neem show the lower input cost as compared to other biodiesel plants. The major input variable costs are manpower, diesel, electricity, fertilizer, and methanol for all the biodiesel plants.

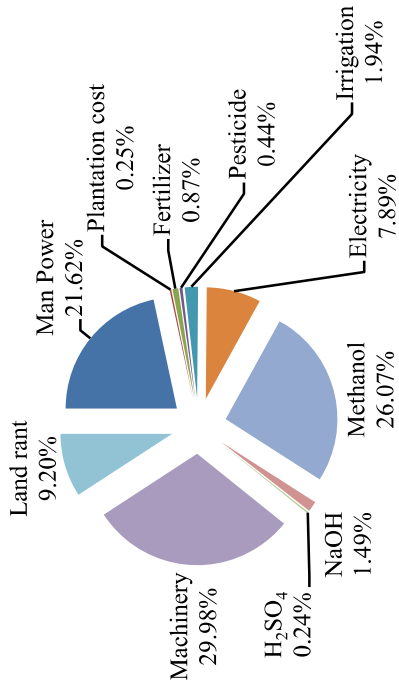
Figure 5.5 shows the distribution of input expenses for the above-selected vegetable plants throughout its biodiesel production. It has been clear from the figure that the manpower, methanol, and electricity shared the major proportion among the different variable input cost. The total income of Jatropha, Mahua, Neem, Palm, Coconut, Karanja, Jojoba and Tung biodiesel plants are 135.58, 169.61, 222.28, 124.70, 141.64, 206.07, 145.97 and 186.84 Rs kg⁻¹, respectively. Among all the plants, Neem, Karanja, Jojoba, and Mahua show better incomes.

Table 5.8: Economic equivalents of input and output in biodiesel production

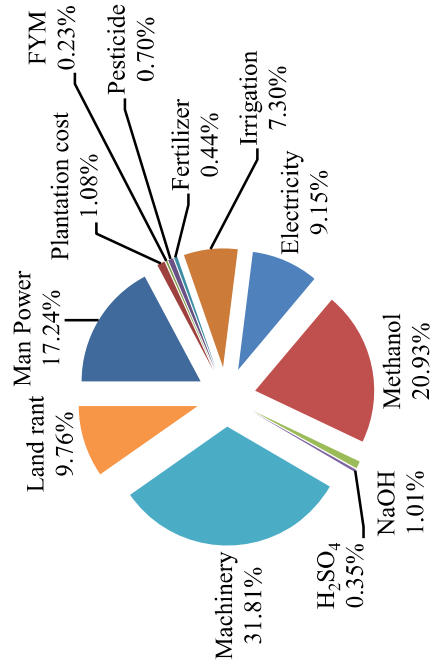
	Quantity (Inputs)		Total cost equivalent (Rs kg ⁻¹)						
	Jatropha	Mahua	Neem	Palm	Coconut	Karanja	Jojoba	Tung	
A. Inputs									
Cultivation									
a) Man Power	13.58066	11.64258	4.687483	10.12202	17.61708	22.24915	11.57625	10.79145	
b) FYM	0.512914	0.17424	0.065489	na	na	0.23531	0.286706	0.594508	
c) Fertilizers	1.923428	0.726083	0.232982	0.975293	1.036344	0.281228	0.531659	0.710519	
d) Irrigation	0.340699	1.306117	0.358264	1.12221	2.310224	0.303375	8.908399	0.751093	
e) Pesticides	0.158452	0.249687	na	1.046809	0.520666	0.107327	0.85679	0.383861	
f) Plantation cost	2.036729	0.170396	0.145258	0.229508	0.300263	0.215948	1.315504	0.764025	
Total cultivation cost (T₁)	18.55289	15.11172	5.489476	13.49584	21.78458	23.29923	22.79926	13.99545	
Oil Extraction									
a) Electricity	6.046371	7.101675	9.128135	4.060049	3.625689	8.325544	4.865995	8.511063	
b) Man Power	4.816555	5.078873	5.234051	2.932988	2.624079	5.94004	3.501559	6.093701	
Total oil extraction cost (T₂)	10.86293	12.18055	14.36219	6.993038	6.249767	14.26558	8.367554	14.60476	
Biodiesel Production									
a) Methanol	22.91641	16.29398	20.43664	21.26656	30.99251	26.57905	25.54583	26.91459	
b) NaOH	1.104478	1.358821	0.632886	0.615126	1.777118	1.16483	1.231503	1.297488	
c) H ₂ SO ₄	0.382319	0.436764	0.432219	0.212928	0.287071	0.201605	0.42629	0.44913	
d) Electricity	5.609641	6.244994	6.300824	5.814169	5.749575	5.590691	6.302686	6.422031	
e) Man Power	5.247947	5.567297	5.917276	5.597084	5.461911	5.352033	5.965552	6.007956	
Total Biodiesel production cost (T₃)	35.26079	29.90186	33.71984	33.50586	44.26819	38.88821	39.47186	41.09119	
Total variable cost (TVC) = T₁+T₂+T₃	64.67661	57.19412	53.5715	53.99474	72.30254	76.45302	70.63867	69.69141	
Fixed cost									
a) Machinery	45.74655	36.5643	18.80065	16.93198	35.64622	20.5398	38.83036	56.21281	
b) Land rant	14.03268	11.21604	5.76707	5.19386	10.93442	6.300552	11.91115	17.24319	
Total fix cost (TFC)	59.77924	47.78035	24.56772	22.12584	46.58064	26.84035	50.74151	73.456	
Total input cost (TVC + TFC)	124.4558	104.9745	78.13922	76.12058	118.8832	103.2934	121.3802	143.1474	
B. Outputs									
a) Biodiesel	93.49627	107.8299	104.8687	96.55751	101.6644	98.53346	104.026	100.5716	
b) Glycerol	10.62520	12.13538	10.13413	9.430427	7.277431	12.44788	11.84414	12.48084	
c) Seed/Oil Cake	31.46128	49.64563	107.2731	18.71308	32.70212	95.09024	30.10486	61.36484	
Total incomes	135.5827	169.6109	222.276	124.701	141.644	206.0716	145.975	186.8362	

Figure 5.5: Distribution of input cost for different plants in biodiesel production (a) Jatrophha (b) Mahua (c) Neem (d) Palm (e) Coconut (f) Karanja (g) Jojoba (h) Tung

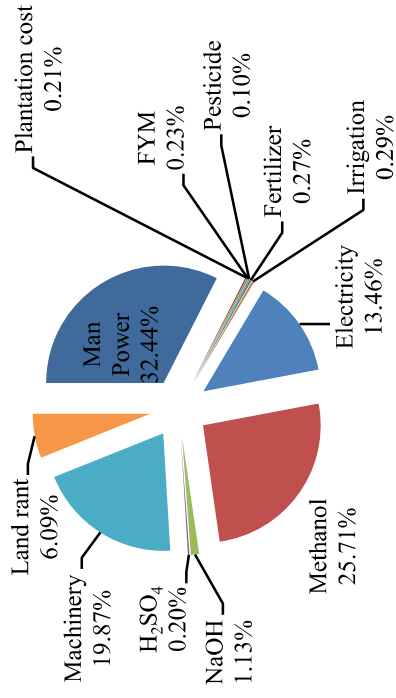




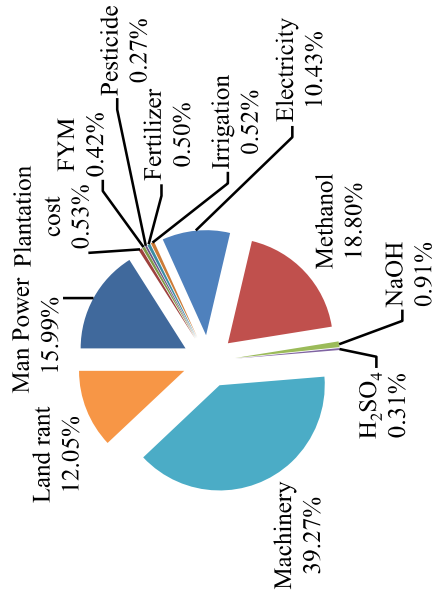
(e) Coconut



(g) Jojoba



(f) Karanja



(h) Tung

5.7.5 Economic indicators

The availability and dependability of energy services are essential to achieve economic growth. There are different sectors of the economy, such as domestic, commercial, transport, services, and agricultural, depend on safe and adequate energy services. The main themes economic indicators are use and patterns of production (includes overall use and productivity, supply efficiency, production, end-use, fuel mix, and prices) and supply security (includes import dependency and strategic fuel stocks). Thus, various economic indicators including gross production value, gross return, net profit, net return, benefit to cost ratio (BC) and productivity are calculated on the basis of the given economic equivalents of the inputs cost, output revenue (table 5.5 and 5.6), and the surveyed data. Mohammadshirazi et al. [2] were given the following expressions for economic analysis.

$$\text{Gross production value} = \text{Yield} \left(\frac{\text{kg}}{\text{kg}} \right) \times \text{Price of commodity} \left(\frac{\text{Rs}}{\text{kg}} \right) \quad (4.9)$$

$$\text{Gross return} = \text{Gross production value} \left(\frac{\text{Rs}}{\text{kg}} \right) \times \text{Variable production cost} \left(\frac{\text{Rs}}{\text{kg}} \right) \quad (4.10)$$

$$\text{Net return} = \text{Gross production value} \left(\frac{\text{Rs}}{\text{kg}} \right) \times \text{Total production cost} \left(\frac{\text{Rs}}{\text{kg}} \right) \quad (4.11)$$

$$\text{BC} = \frac{\text{Gross production value (Rs/kg)}}{\text{Total production cost (Rs/kg)}} \quad (4.12)$$

$$\text{Productivity} = \frac{\text{Yield (kg/kg)}}{\text{Total production cost (Rs/kg)}} \quad (4.13)$$