Research Article

Economic feasibility of biodiesel production from Pongamia Oil on the Island of Vanua Levu

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Abstract
This study presents the economic feasibility of biodiesel production from Pongamia oil, which can be potentially produced from approximately 58,897 ha of unutilized marginal lands available on the Island of Vanua Levu. The production analysis shows that approximately 488 million litres of Pongamia oil and 645 million litres of biodiesel can be produced from the total available land area. A cost–benefit analysis carried out to investigate the viability of such project displays a positive net present value and a benefit–cost ratio greater than 1 at all the discount rates up to 10%. The implications of economic feasibility for this project was investigated by carrying out sensitivity analysis, which shows that the project will be viable up to 5% discount rate with at least 5% increase in net present cost. The study projects large scale Pongamia biodiesel production from total available land area, however, such venture can be scaled down to some suitable scale of production at any lower costs upfront to substitute or blend Pongamia biodiesel with neat diesel for running inter-island shipping vessels, fishing boats and providing household electrification in the outer and remote islands of Pacific Island Countries.

Keywords Pongamia biodiesel · Cost–benefit analysis · Cost of biodiesel · Net present value · Benefit–cost ratio

1 Introduction

An escalating increase in energy demand due to rising population and forecasted shortage of fossil fuel reserves has contributed towards significant rise in the market price of fuel. The impact of this scenario has become a major problem for the developing countries like Pacific Island countries (PICs) due to absence of indigenous fossil fuel resource [1]. Such countries are left with the only option to import these fuels at high costs in order to cater for energy needs in rural and outer islands for household electrification, operating inter-island shipping vessels and running fishing boats. Biofuels, in particular biodiesel, is given great attention as an alternative fuel that could replace or blend with neat diesel to cater for such energy needs using diesel engine [2, 3].

Biodiesel can be produced from vegetable oils by the process of transesterification to lower the viscosity of vegetable oil [4]. In the production cycle of biodiesel, refined vegetable oil triglycerides (long chain fatty acids) react with alcohol, such as methanol or ethanol, in presence of sodium hydroxide (NaOH) or potassium hydroxide (KOH) catalyst to form esters [5, 6]. The ester is finally dried by heating and the end product is achieved as biodiesel. The glycerol byproduct is also useful for medicinal purposes [7]. When tested on diesel engine, it has been noted that the engine performs satisfactorily on biodiesel fuel without any significant engine hardware modification and with reduced emissions of greenhouse gases [8, 9].

Although the science of biodiesel production and has become vital, understanding the economics of the production process is equally urgent. Biodiesel production

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project will be profitable if the net present cost (NPC) for producing biodiesel will be less than the net present benefit (NPB). However, for long term viability of such project, economic analysis needs to be conducted by verifying some essential parameters, such as levelised cost of biodiesel (LCOB), cost of biodiesel (COB), net present value (NPV), discount rates, internal rate of return (IRR), simple payback period (SPP) and benefit to cost ratio (BCR) [10, 11].

Biodiesel production from Pongamia oil has been receiving more focus as a suitable candidate to substitute diesel fuel recently as the oil is inedible and such property of oil erases the food versus fuel controversy due to its unsuitability in the food industry [12, 13]. Furthermore, Pongamia trees have the ability to survive in tropical climates, on marginal lands and on many types of soils, including both acidic and alkaline soils [14–16]. Although Pongamia seems to be a better alternative for biodiesel production, one needs to determine whether it is physically viable to produce Pongamia biofuels in PICs.

2 Materials and methods

Some possible sites for raising Pongamia plantation were identified using Google Earth Pro software, using the land utilization information gathered from the Department of Land Use. The land utilization information were further gathered from other sources [17, 18]. The yield of Pongamia seed production was determined by considering 49.5 seeds/tree at an average seed weight of 9–90 kg/tree [3]. Moreover, Pongamia plantation was considered at 500 trees/ha [19].

The yield of Pongamia oil extracted from the seeds using oil expelling machinery were determined by considering 31% (w/w) of oil per seed [14, 20]. The oil refining process would involve degumming of crude oil using phosphoric acid in the range of 0.05–1% to remove gums [21]. It was assumed that 1.073 ton of crude oil yeilds 1 ton of refined oil [22].

The yield of biodiesel produced using Pongamia oil and methanol was determined using most common stoichiometry description of transesterification reaction [23], as shown in Fig. 1. The catalyst requirement has been estimated at 1.5% of the oil quantity.

The cost breakdown analysis of Pongamia biodiesel production was carried out in three stages, namely farming, oil extraction/refining and biodiesel production. All costs were estimated as at the year 2017. The costs incurred in farming stage mainly included costs on land clearing, road access, raising seedlings, transplanting, weed control, harvesting, transporting, labor and trucks. The farmers would also be paid for their profit for raising Pongamia farms at $210.15/ton of Pongamia seeds.

1000 kg of oil + 110 kg of methanol —NaOH (1.5% of oil (w/w))→ 1000 kg of biodiesel + 110 kg of glycerol

Fig. 1 Transesterification of oil and methanol with NaOH catalyst to produce biodiesel

The costs incurred in oil extraction and refining was inclusive of costs on building, decorticators, oil press machines, oil extraction/refining equipment and installation, labor/expertise, depreciation, operational and maintenance (including electricity), production input (phosphoric acid and water), analysis and others. The costs of oil refining equipment, operations and maintenance was estimated using the costing done for oil refining factory in Samoa [21].

For the production of biodiesel, the cost breakdown included costs on equipment, delivery, installation, building, service facilities, engineering supervision, legal expenses, contractors, operational and maintenance, insurance, labor, plant overhead cost, contingency, depreciation and production input (methanol and NaOH). All such costs were estimated using the costing done for a 10,000,000 kg/year of biodiesel production unit on Crete Island [23]. Other costs in general included costs on land acquisition and working capital.

The biodiesel production projects lifetime was considered at 20 years, which is equal to the life span of oil refining and biodiesel production factory [24, 25]. A cost benefit analysis was carried out using net present cost (NPC) and net present benefit (NPB) to determine a suitable cost of biodiesel (COB) at which a positive net present NPV could be obtained up to 10% discount rates. The simple payback period (SPP), internal rate of return (IRR) and benefit cost ratio (BCR) were also verified for long term viability of such project.

3 Theory regarding economic analysis parameters

Biodiesel production project will be profitable if the NPC for producing biodiesel will be less than the NPB. However, for long term viability of such project, economic analysis needs to be conducted by verifying some essential parameters, such as levelised cost of biodiesel (LCOB), COB, NPV, discount rates, IRR, SPP and BCR [10, 11].

The LCOB is expressed as the sum of costs during a selected time period divided by annual yield of biodiesel, as given in the following equation:

$$\text{LCOB} = \frac{\sum \text{costs/Number of years}}{\text{Annual yield of biodiesel (L)}}$$

Source : [26]

The LCOB is independent of any discount factors. However, the COB takes into account the discount factors while determining the NPVs within the lifetime of biodiesel production. The NPV compares the value money today with the value of same amount of money in future by considering the inflation and returns. If NPV is positive, a project will be profitable. However, a negative NPV indicates that the project will incur a loss. The NPV is determined using the following equation:

$$\text{NPV} = \frac{\sum \text{benefits}_n - \sum \text{costs}_n}{(1+i)^n}$$

Source : [26]

The variable, i and n in the NPV equation represent discount rate and number of years, respectively. Moreover, the IRR is a discount rate at which the NPV is equal to zero. At such discount rate, NPB is equal to NPC. A project is profitable if the discount rate is less than IRR and the NPV is positive. The BCR is the ratio of the NPB to the NPC of a project in a given period of time, as given in the following equation.

$$\text{BCR} = \frac{\text{Net present benefit}}{\text{Net present cost}}$$

Source : [27]

The SPP period refers to time taken to recover the investment costs of biodiesel production project. Such project becomes viable if the payback period is less than its lifetime. To account for the discount rates due to time value of money, SPP is determined as the x-intercept of the discounted cash flow curve [26].

4 Results

4.1 Production potential for Pongamia oil in Vanua Levu

The island of Vanua Levu has high potential for Pongamia farming. The total available land area for raising Pongamia plantations have been identified to be approximately 58,897 ha, which are spread in 8 different sites, as shown in Fig. 2.

Using the total available land, approximately 1,453,889,250 kg of Pongamia seeds can be produced. At such capacity of seed production, 488,834,780.40 l of crude oil and 453,885,589.90 l of refined oil can be obtained. Transesterification of refined Pongamia oil and methanol with NaOH catalyst will yield approximately 645,602,367.80 l of biodiesel using the total available land.

4.2 Cost–benefit analysis

The analysis of cost summarizes the investment costs and variable costs during Pongamia farming, oil extraction/refining and biodiesel production using the total available land area in Table 1. At such large scale production, a total investment cost of $1,122,669,691.78 is prerequisite. The net present cost at 0% discount rate is $874,571,693.25.

5 Discussion

5.1 Outcomes of cost–benefit analysis

The cost–benefit analysis shows that the levelised cost of biodiesel (LCOB) is $1.44/l and at such LCOB, the BCR is 1.06. A BCR greater than 1 indicates that biodiesel production project will be profitable. However, the LCOB is independent of any discount factors, which are essential to account for the NPVs within the 20 years lifetime of biodiesel production. Henceforth, the COB has been determined by analyzing the NPVs at a maximum selected discount rate of 10%, as shown in Table 2. At a LCOB of $1.44/l, the NPV is negative, which indicates that a loss will be incurred within the lifetime of biodiesel production. The cash flow analysis indicates that the NPV is zero when the COB is very close to $1.56 at a discount rate of 10%. When NPV is zero, the discount rate is equal to IRR and at such NPV, no profit will be made over the 20 years lifetime of biodiesel production, as the total benefits will be equal to total cost. At such COB, the SPP will be the lifetime of biodiesel production, which in this case is 20 years. Thus the market price or the COB for the consumers has been selected at $1.57 in Vanua Levu. At such COB, a positive NPV is obtained at an IRR of 10.8%, which is greater than the discount rate. In order to have a viable biodiesel production project, it is vital for the discount rate to be less than IRR. The SPP is obtained as 18 years and it decreases as the COB increases. To have low SPP, the COB will be high and expensive for the consumers to afford. The COB at $1.57 is also comparable with the market price of neat diesel. The average market price for neat diesel as at the year 2017 is $1.57/l in Fiji [28]. Moreover, the BCR at a COB of $1.57 is determined to be 1.16, which is greater than 1.

The SPP has been determined by identifying the x intercept of discounted cash flow curves. For instance, Fig. 3 shows the discounted cash flow curve with SPP of approximately 18 years and COB of $1.57 at a discount rate of 10%.

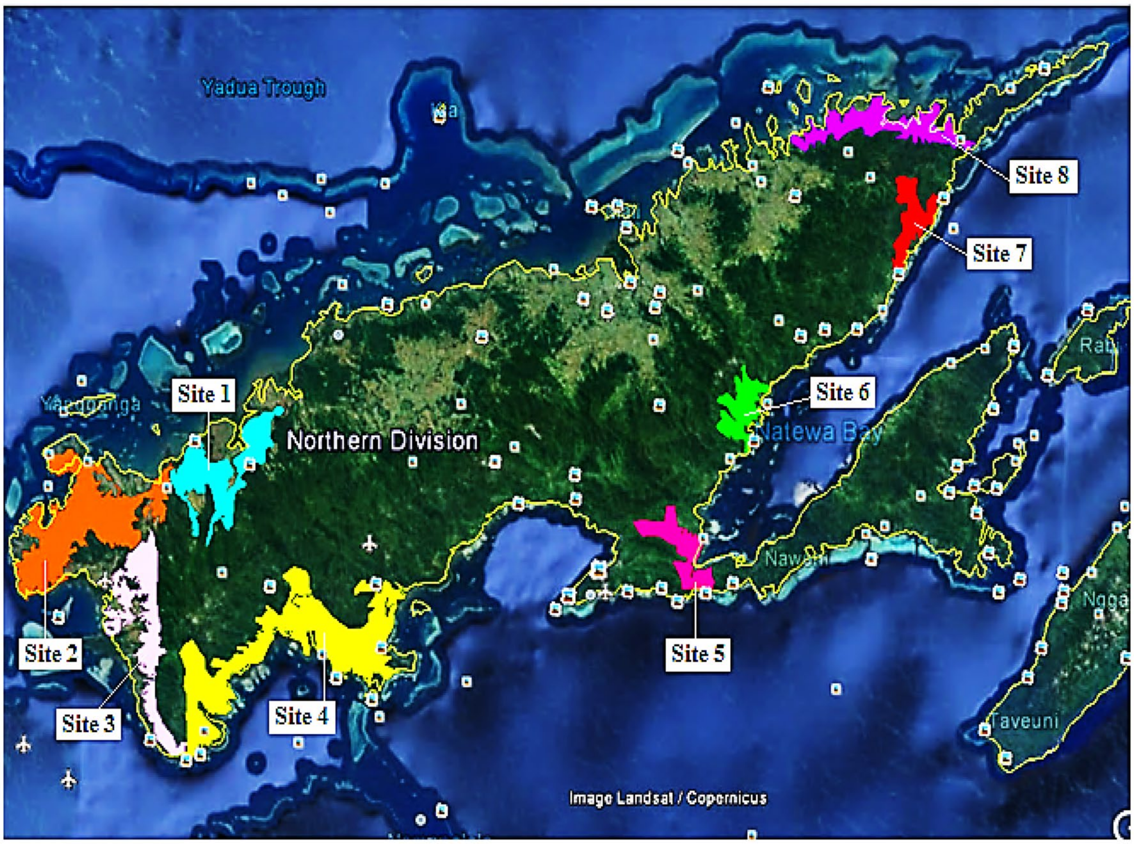

Fig. 2 Map showing 8 possible Pongamia plantation sites in Vanua Levu

At constant COB ($1.57/l), the NPV, IRR and SPP of biodiesel production have been also studied for different discount rates, as shown in Table 3. While the NPV decreases at increasing discount rates, the IRR is constant at 10.79%, which is higher than the selected discount rate of 10%. SPP is ranging from 9 years up to a maximum of 18 years, which is also within the lifetime of biodiesel production project. The analyses of NPV, IRR and SPP at different discount rates indicate the viability of such project at a reasonable COB of $1.57/l.

5.2 Sensitivity analysis

The sensitivity analysis takes into account the implications of economic feasibility and their impacts on the viability of biodiesel production project. A cost–benefit analysis has been carried out to investigate the effect of adjusting various assumptions on the key economic indicators, i.e. NPV, IRR and SPP. The assumptions were adjusted one at a time, with all other assumptions held constant.

5.2.1 Analysis with net present benefit inclusive of benefits from sales of glycerol

Biodiesel production project will receive further benefits by selling glycerol. The average selling price of glycerol is approximately $281.41/ton [23]. The cost–benefit analysis at COB of $1.57 with benefits from glycerol is shown in Table 4. The biodiesel production project has a positive NPV up to a discount rate of 28% with a maximum SPP of 17 years and an IRR that is more than the discount rate. The BCR at such COB is determined to be 1.37.

The NPC of biodiesel production will be further reduced from the profit earned through the sales of glycerol as byproduct. According to Fig. 4, the return shares from sales of glycerol reduce the NPC by 17.16%, which further increases the NPV and decreases the SPP.

5.2.2 Analysis excluding investment cost (with net present cost (NPC)

If the investment costs are excluded from the analysis, the feasibility of operations alone could be assessed. The

Table 1 Cost analysis for Pongamia biodiesel production as at the year 2017

Parameter	Cost
Investment cost	
Farming stage:	
Land clearing and road access	$80,080,312.00
Raising seedlings	$9,604,417.19
Transplanting	$88,802,995.24
Weed control	$5,895,500.00
Trucks (8 ton) for transportation at all stages	$21,000,000.00
Oil extraction and refining stage:	
Building	$10,564,983.00
Decorticators	$2,543,198.64
Oil press machines	$ 70,216,099.80
Oil extraction/refining equipment and installation	$230,501,516.61
Biodiesel production stage:	
Equipment	$144,458,160.00
Equipment delivery and installation	$50,560,356.00
Instrumentations and controls	$11,866,206.00
Piping	$43,337,448.00
Electrical systems	$21,668,724.00
Buildings	$21,668,724.00
Yard improvement	$14,445,816.00
Service facilities	$43,337,448.00
Land acquisition	$14,445,816.00
Engineering supervision	$43,337,448.00
Legal expenses and contractor fees	$7,222,908.00
Working capital	$187,111,615.30
Total investment cost	$1,122,669,691.78
Variable cost	
Farming stage	
Harvesting and transport	$118,989,953.59
Payment for Pongamia seeds (profit for farmers)	$305,534,825.90
Oil extraction and refining stage:	
Labors/expertise	$86,486,003.10
Operational and maintenance cost	$22,610,333.24
Depreciation	$27,199,548.73
Production input cost	$535,390.52
Analysis and others	$10,564,983.00
Biodiesel production stage:	
Production input cost	$171,325,055.17
Operational and maintenance cost	$14,445,816.00
Property insurance	$6,566,280.00
Labor	$39,397,680.00
Plant overhead costs	$26,265,120.00
Contingency	$11,819,304.00
Depreciation	$32,831,400.00
Total variable cost (net present cost)	$874,571,693.25

Table 2 Variation of COB and its effect on NPV, IRR and SPP

COB ($/l)	NPV ($)	IRR (%)	SPP (years)
1.44	−653,608,799.68	0	–
1.54	−103,971,110.09	8.62	–
1.55	−49,007,341.13	9.36	–
1.56	5,956,427.83	10.08	20
1.57	60,920,196.79	10.79	18
1.58	115,883,965.75	11.49	16
1.59	170,847,734.71	12.17	15
1.60	225,811,503.67	12.85	13

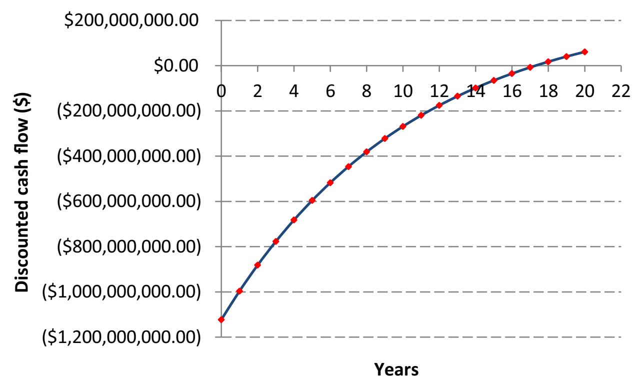

Fig. 3 Analysis of SPP using a discounted cash flow curve at COB of $1.57

Table 3 Variation of discount rate and its effect on NPV, IRR and SPP

Discount rate (%)	NPV ($)	IRR ($)	SPP (years)
1	1,386,095,700.43	10.79	9
2	1,150,572,33.16	10.79	9
3	945,656,733.2	10.79	10
4	766,712,166.83	10.79	10
5	609,876,940.42	10.79	11
6	471,924,93.24	10.79	12
7	350,152,801.02	10.79	13
8	242,288,670.95	10.79	14
9	146,477,462.19	10.79	16
10	60,920,196.79	10.79	18
11	−15,575,770.91	10.79	–

cost–benefit analysis of such scenario becomes vital if the capital costs are funded by some donor agencies. By eliminating the investment costs, the analysis only involves costs associated with maintaining and operating the project such as administrative costs, transport costs and some others. The cost–benefit analysis at COB of $1.57, excluding investment cost, is shown in Table 5. Exclusion

Table 4 Cost benefit analysis including benefits from sales of glycerol

Discount rate (%)	NPV ($)	IRR (%)	SPP (years)
10	1,603,274,939.97	28.33	5
20	436,513,415.35	28.33	7
25	143,317,957.38	28.33	10
28	12,656,001.96	28.33	17
29	− 25,351,391.09	28.33	–

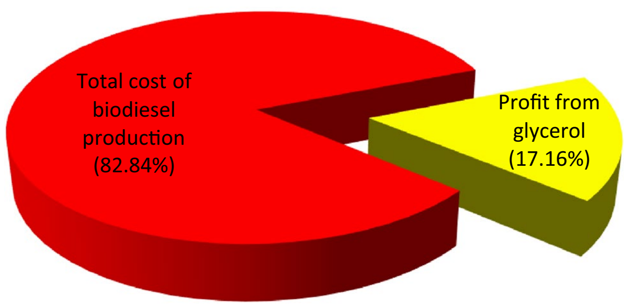

Fig. 4 Return shares from glycerol as byproduct in Pongamia biodiesel production

Table 5 Cost benefit analysis excluding investment cost

Discount rate (%)	NPV ($)	IRR (%)	SPP (years)
5	1,732,546,632.20	–	–
10	1,183,589,888.57	–	–
20	676,988,570.69	–	–
30	460,975,033.05	–	–

of investment costs eliminates any need for analysis of SPP to cover such costs. The BCR at COB of $1.57 is determined to be 1.16.

The analysis of NPC has been carried out to outline the major expenditure in biodiesel production, as shown in Fig. 5. The payment costs of purchasing Pongamia seeds (which is the profit for farmers) is highly significant as it accounts for approximately 34.9% of NPC. The cost on labor is also quiet high with 26.5% of NPC.

5.2.3 Analysis using increased net present cost (NPC)

During the 20 years of economic lifetime, the NPC for operating biodiesel production project are subject to changes. These variable costs would increase with the increase in any maintenance cost, labor charges,

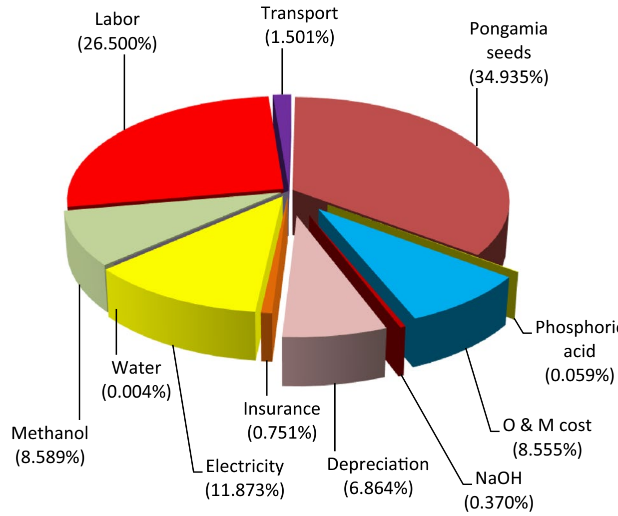

Fig. 5 Analysis of NPC in Pongamia biodiesel production from total available land

Table 6 Cost benefit analysis with increase in net present cost

Discount rate (%)	NPC (% increase)	NPV ($)	IRR (%)	SPP (years)	BCR
5	1	500,885,976.41	9.82	12	1.15
	3	282,904,048.39	7.82	15	1.13
	5	64,922,120.37	5.67	19	1.10
6	1	371,612,229.02	9.82	13	1.15
	4	70,674,176.37	6.76	18	1.11
	5	− 29,638,507.84	5.67	–	1.10
7	1	257,500,551.25	982	14	1.15
	3	72,196,051.71	7.82	18	1.13
	4	− 20,456,198.06	6.76	–	1.11
8	1	156,421,932.93	9.82	16	1.15
	2	70,555,194.9	8.83	18	1.14
	3	− 15,311,543.13	7.82	–	1.13
9	1	66,581,785.77	9.82	18	1.15
	2	− 13,253,890.66	8.83	–	1.14
10	1	− 13,537,021.59	9.82	–	1.15

electricity and water costs, price of Pongamia oil as feedstock, price of methanol, price of NaOH, etc. The cost–benefit analysis at COB of $1.57 carried out up to 5% increase in NPC is shown in Table 6. A positive NPV is obtained up to 5% increase in NPC at 5% discount rate. However, a negative NPV is obtained when the NPC increases just by 1% at 10% discount rate. At other discount rates of 6%, 7%, 8% and 9%, a positive NPV is obtained at 4%, 3%, 2% and 1% increase in NPC, respectively. The BCR due to rise in NPC at discount rates up to 10% is greater than 1.

Table 7 Cost benefit analysis with rise in diesel fuel cost

Discount rate (%)	COB (% increase)	NPV ($)	IRR (%)	SPP (years)	BCR
1	1	1,566,854,403.89	11.87	8	1.17
	5	2,289,889,217.72	15.98	7	1.22
3	1	1,094,681,430.39	11.87	9	1.17
	5	1,690,780,219.16	15.98	7	1.22
5	1	734,708,414.85	11.87	10	1.17
	5	1,234,034,312.58	15.98	8	1.22
7	1	456,270,927.91	11.87	12	1.17
	5	880,743,435.46	15.98	8	1.22
10	1	146,198,865.87	11.87	15	1.17
	5	487,313,542.19	15.98	10	1.22

5.2.4 Analysis using rising diesel fuel costs

According to the US Energy Department's Energy Information Administration forecast, high crude oil prices are expected for the next 20 years [29]. The cost–benefit analysis has been carried out up to 5% rise in the market diesel fuel price. The rise in COB has been assumed to be equal to the rise in cost of diesel (COD). The cost–benefit analysis with rising fuel cost is shown in Table 7. The NPV increases with an increase in NPB due to increase in COB. The BCR with rising COB and COD up to 10% discount rates are greater than 1.

5.2.5 Analysis using investment costs without farming costs

Pongamia trees yield fruits up to approximately 65 years [30]. The plants can be utilized thrice if one life span of biodiesel production is considered at 20 years. However, Pongamia farming will not be required in the second and third lifespan of biodiesel production, so farming costs (except for cost of purchasing trucks) can be eliminated from the investment cost. The cost–benefit analysis excluding farming cost for second and third life span of biodiesel production at a COB of $1.57 is shown in Table 8. A positive NPV is obtained up to 13% discount rate by eliminating farming costs during second and third life span of the project. The discount rate of 13% is less than an IRR of 13.68% and the SPP is up to a maximum of 18 years. The BCR at such COB is determined to be 1.16.

5.3 Selecting suitable scale of biodiesel production

The cost–benefit analysis has been carried out for total available land area that projects large scale Pongamia biodiesel production. Such scale of production requires

Table 8 Cost benefit analysis with investment cost without farming costs

Discount rate (%)	NPV ($)	IRR ($)	SPP (years)
10	$245,303,421.22	13.68%	12
11	$168,807,453.52	13.68%	13
12	$100,145,643.81	13.68%	15
13	$38,322,766.01	13.68%	18
14	– $17,512,205.29	13.68%	–

huge capital investment, which would be very difficult for funding. To cater for this, the project can be scaled down to some suitable scale of production at any lower costs upfront. Furthermore, the cost of investment can be fully or partially funded by some donor agencies and/or by government assistance to replace diesel fuel with a cleaner source of energy that is environmental friendly and sustainable.

5.4 Benefits of biodiesel production from Pongamia Oil in Fiji

While Pongamia survives well in tropical climate of Fiji, it has other added benefits as an oil feedstock for producing Pongamia biodiesel. Biodiesel has been previously produced in Fiji using coconut oil but such production leads to food versus fuel controversy [31]. Pongamia oil need not to be debated for food versus fuel issue as this oil cannot be utilized in food industry for the people. Pongamia oil is inedible and contains some toxic components that are not suitable for human food [12, 13]. The use of Pongamia oil as a feedstock in the fuel industry would solve the issue of food versus fuel, which currently exists in the case of coconut oil. Coconut oil and Pongamia oil have been tested for their fuel properties in Fiji [32, 33] and the latter displayed better fuel characteristics. The results from such study showed that the Gross Calorific Value (GCV) of coconut oil and Pongamia oil is 38.68 MJ/kg and 39.27 MJ/kg, respectively. While, both the types of oil showed similar performance on diesel engine, Pongamia oil showed slightly reduced emissions of Carbon Dioxide (CO_2), Carbon Monoxide (CO) and Nitrogen Oxide (NO_x) emissions in comparison with that of coconut oil.

Small scale Pongamia oil production project has already commenced in Fiji on approximately 154 Ha of land and Pongamia oil has been extracted using oil expellers. However, once the Pongamia plantation project expands and Pongamia oil is produced at a suitable scale, it will become feasible to install a biodiesel production factory to produce Pongamia biodiesel for meeting the energy needs in remote and outer islands of Fiji, as well as PICs in terms of household electrification, operating inter-island shipping vessels and running fishing boats.

6 Conclusion

The production of Pongamia biodiesel using Pongamia oil produced from approximately 58,897 ha of unutilized marginal lands available on the Island of Vanua Levu is economically feasible. Complete utilization of total available land for Pongamia farming has the capacity to produce 488,834,780.40 l of crude oil. Such production of oil feedstock will yield approximately 645,602,367.80 l of biodiesel. The cost–benefit analysis shows that the project will be profitable up to a discount rate of 10% with a positive NPV and a BCR greater than 1. The implications of economic feasibility for this project investigated by carrying out sensitivity analysis shows that the project will be viable up to 5% discount rate with at least 5% increase in net present cost. The study projects large scale Pongamia biodiesel production from total available land area but such venture can be scaled down to some suitable scale of production at any lower costs upfront. Production of Pongamia biodiesel at a suitable large scale has the potential to substitute or blend with neat diesel to meet the energy requirements for household electrification, operating inter-island shipping vessels and running fishing boats in remote and outer islands of PICs.

Although the economic feasibility analysis indicates that Pongamia biodiesel production project is physically viable, a detailed Life Cycle Analysis (LCA) needs to be conducted to investigate the emissions of greenhouse gases during all the stages of production, prior to the commencement of actual project.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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