Assessing Environmental and Economical Suitability of Ethanol Production from Rice Straw for Sri Lanka

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Introduction:

Sri Lanka is having a rapid rate of development after disastrous period due to war inside the country. Sri Lanka imports 4 million tons of crude oil and refined products for its energy needs and it's more than 20% of annual import bills [(1)]. Sri Lanka depends totally on crude oil imports for transportation sector. So the need of new clean technologies using Sri Lanka's resources is essential to minimize the dependency on fossil fuel to make Sri Lanka self-sufficient as an initial step of the way of achieving sustainable economy. Selection of the raw material which doesn't compete with increasing food prices and arable land usage issues is important to consider. So bio-ethanol production from rice straw has a high potential for Sri Lanka due to high availability as a waste. Sri Lanka has an increasing rate of paddy production which secures rice straw availability as the amount of straw generation is equal to the amount of paddy production.

Problem Identification

Although bio-ethanol production is very important for Sri Lanka, decision makers (public and government officials) are not knowledgeable about using ethanol as a fuel. So decision making stage is very unstable to establish production plants inside the country. Still no research has been performed to identify environmental and economical suitability of ethanol production from rice straw for Sri Lanka to provide guidance for decision makers.

Goals and Objectives

The goal of this research is to find out the environmental and economical suitability of bio-ethanol production process from rice straw for Sri Lanka with aiming to provide guidance for decision makers. To reach the goal there are objectives to achieve. Below are those objectives:

1) Assess the environmental impacts and economic values of a selected ethanol production technology
2) Assess the environmental impacts and economic values of proposed alternative production technologies
3) Identify suitable production methods for Sri Lanka considering environmental and economic issues.

Methodology

In this study, literature survey was performed for gathering data from four ethanol production plants which use rice straw as main raw material in Hokkaido, Hyogo and Chiba prefectures of Japan. From those production plants, ethanol production process of Kashiwanoha ethanol production plant in Chiba prefecture was selected for the assessment. Also as this study focusing on importing an established ethanol production from rice straw in Japan for Sri Lanka, to have a comparison among Japan and Sri Lanka, data related to the climate, economic and resource availability situations of Japan and Sri Lanka are gathered.

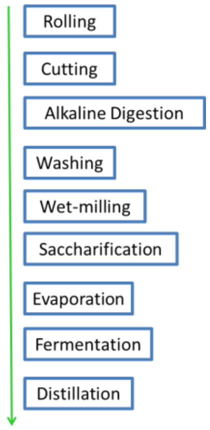
For the selected ethanol production process which uses alkaline digestion as the pretreatment method, environmental impact assessment has been performed as scenario 1, by using SimaPro software and Microsoft Excel sheets considering 10 impact categories. After identifying environmental impacts of the process, possible alternative production methodology which uses another pretreatment method that can be suitable for Sri Lanka is proposed as scenario 2 (hydrothermal treatment) and environmental impacts have been assessed. Further, usage of lignin rich residue as the boiler fuel for above two production methodologies (Alkaline Digestion; AD and Hydrothermal Treatment; HT) as scenario 3 and 4, environmental impacts have been assessed to identify environmentally feasible scenario for Sri Lanka. Economic assessments for all four scenarios also have been performed to identify economically favorable scenario for Sri Lanka. With the conclusions from above assessments and considering the paddy production areas and straw availability in Sri Lanka, suitability of above four scenarios has been discussed with environmental and economic issues as guidelines for decision makers.

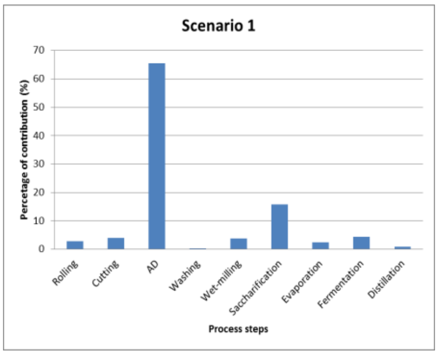
Results and Discussion

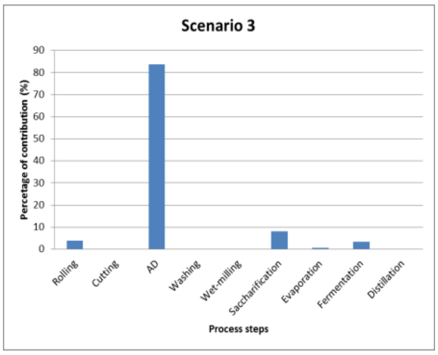
For the environmental and economic assessments, ethanol production capacity of the plant is taken as 2250 kl per year, production capacity of scenario 1 and 3 is 75 l of ethanol from 1 ton of rice straw whereas the production capacity of scenario 2 and 4 is 114 l of ethanol from 1 ton of rice straw.

Environmental Impact Assessment

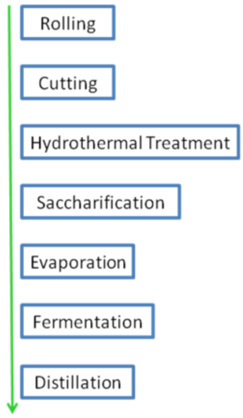
Environmental impacts have been assessed considering 10 impact categories for each scenario. The percentage contributions of process steps for each scenario are showed in below figures.

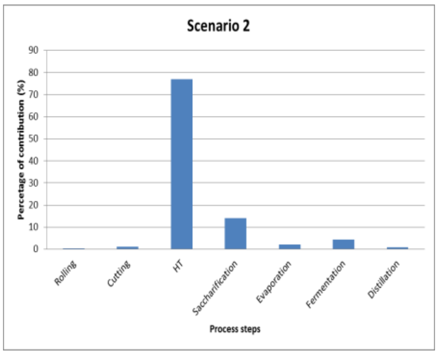


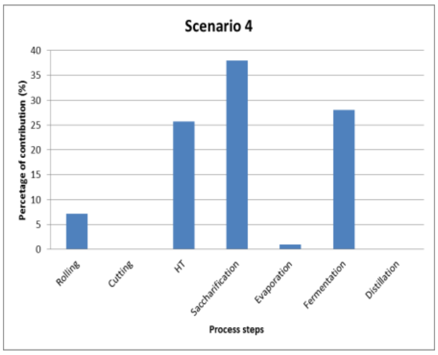




Process flow for scenario 1 and 3







Process flow for scenario 2 and 4

Percentage of contribution from process steps for 1t of ethanol production

For scenario 1, 2 and 3, pretreatment step shows highest percentage of contribution than other process steps. For scenario 4, pretreatment step shows less percentage of contribution and saccharification process step has the highest percentage of contribution.

Impact category	Unit	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Abiotic depletion	kg Sb eq	43.46	61.51	27.61	1.80
Acidification	kg SO2 eq	23.90	14.60	18.00	12.25
Eutrophication	kg PO4--- eq	6.28	1.17	6.29	1.62
Global warming (GWP100)	kg CO2 eq	5749.79	7538.47	3793.23	477.33
Ozone layer depletion (ODP)	kg CFC-11 eq	0.00091	0.00109	0.00044	0.00006
Human toxicity	kg 1,4-DB eq	2007.81	1288.64	1519.85	50.60
Fresh water aquatic ecotox.	kg 1,4-DB eq	154.40	82.15	121.68	5.18
Marine aquatic ecotoxicity	kg 1,4-DB eq	667867.80	512089.30	477561.16	13197.01
Terrestrial ecotoxicity	kg 1,4-DB eq	27.28	13.97	17.89	0.45
Photochemical oxidation	kg C2H4	1.06	1.06	1.49	3.24

Environmental impact values of the total process

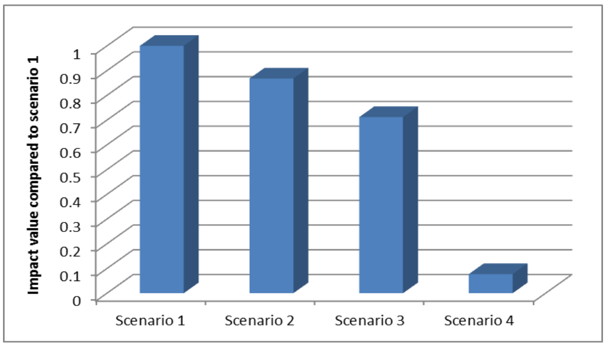
Considering environmental impact values of the total process table, scenario 4 shows lowest impact values for all impact categories other than eutrophication and photochemical oxidation. Photochemical oxidation has highest value in scenario 4 and lowest value in scenario 1 although all the other impact categories have highest values in scenario 1. For eutrophication lowest value gives in scenario 2 whereas scenario 3 shows highest value.

Compared to scenario 1 and 2, environmental impacts have been decreased by scenario 3 and 4. There is a 21% total percentage of impact reduction from scenario 3 compared to scenario 1, whereas scenario 4 reduces total impacts compared to scenario 2 by 44%.

Due to the production process is similar in scenario 1 with scenario 3 and scenario 2 with scenario 4, the energy consumption is also similar in those scenarios. So focusing on energy requirements, below table shows that scenario 2 has higher energy consumption than scenario 1 due to the high energy requirement in pretreatment step (hydrothermal treatment). So, alkaline digestion is beneficial as a pretreatment process than hydrothermal treatment in case of energy consumption.

	Energy requirement (MJ and %)	
Process step	Scenario 1	Scenario 2
Rolling	1065.6 (0.7%)	666 (0.1%)
Cutting	3240 (2%)	2160 (0.4%)
Pre-treatment	28855.6 (20%)	457000 (79%)
Saccharification	79680 (54%)	79680 (14%)
Evaporation	15760 (11%)	15760 (3%)
Fermentation	15760 (11%)	15760 (3%)
Distillation	2340 (1.3%)	2340 (0.5%)
Total	146701.2	573366

Energy consumption

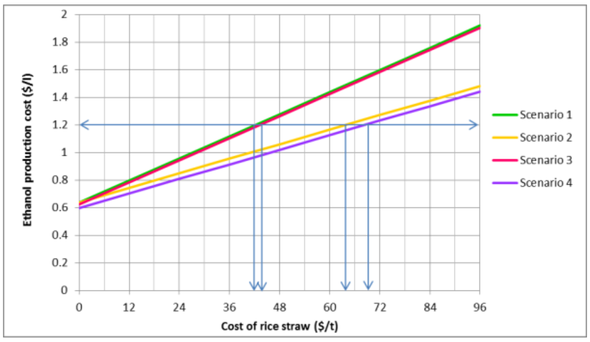


Total impact values comparison with scenario 1

From total impact values comparison with scenario 1 figure, it can be undoubtedly decided that scenario 4 which has the lowest impact values, is the most environmentally friendly ethanol production methodology. The least favorable method is scenario 1 considering the environmental impacts.

Economic Assessment

For the economic assessment, ethanol production costs, capital costs and annual income from ethanol are considered. Assumptions used for this economic assessment are; non-fuel operating and maintenance costs of natural gas boiler and biomass boiler are equal values for every year, ethanol selling price is 1.2 $/l and annual income for the plant is a fixed value for each scenario for every year.



Production cost with cost of rice straw

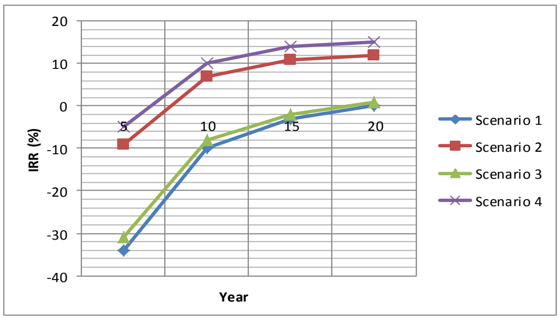
This figure shows the impact on ethanol production cost by the cost of raw material. The production cost shows a linear relationship with the cost of rice straw. Scenario 1 and 3 show high ethanol production values than in scenario 2 and 4 for the same rice straw prices. The rate of change of ethanol production cost over cost of rice straw is higher for process with alkaline digestion than the process with hydrothermal treatment.

Considering the economic values of raw material cost, applying hydrothermal treatment as the pretreatment method is advantageous than alkaline digestion. In scenario 1 and 2, natural gas fired boilers have been used for the operation and for scenario 3 and 4, use of lignin rich residue as the fuel in biomass boilers is concerned. To discuss the economic feasibility of four scenarios, Present Value (PV), Net Present Value (NPV) and Internal Rate of Return (IRR) economic factors are concerned. The cost of the rice straw is taken as 36 $/t in Sri Lanka.

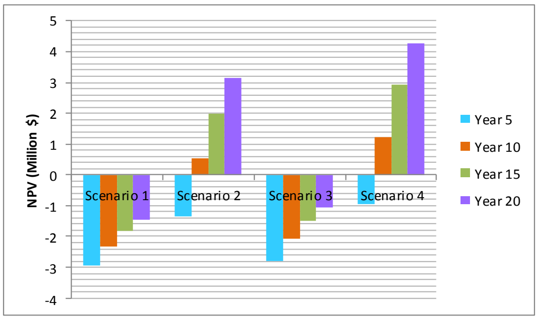
Details	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Unit
Production cost	1.12	0.95	1.10	0.91	$/l
Plant capacity	7500	7500	7500	7500	l/day
Annual plant capacity	2250	2250	2250	2250	kl/yr
Energy requirement	146701	574446	146701	574446	MJ/day
Type of boiler used	Natural gas	Natural gas	Biomass	Biomass	
No. of boilers needed	1	1	1	1	
Capital cost for boilers	17100	36100	19300	35500	$
Cost for fuel	30545.328	90518.472	0	0	$/yr
Annual production cost	2.5178	2.1483	2.4872	2.0578	M$
Initial capital cost	3717100	3736100	3719300	3735500	$
Annual income from the ethanol	2.7	2.7	2.7	2.7	M$/yr

Details of economic assessment

Scenario 2 and 4 requires much energy than scenario 1 and 3 due to high energy necessity of hydrothermal process. Scenario 4 has lowest and scenario 1 has highest production cost as a result of raw material requirements are different due to efficiency difference of those two production methods and the difference in the boiler fuel costs.



IRR change with time



NPV change with time

From the NPV and IRR figures, scenario 1 and 3 show negative values; indicating that these two scenarios are not profitable for selling price of ethanol for 1.2 $/l with the rice straw cost of 36$/t. The best values are showed by fourth scenario. Scenario 2 also has noticeably high values. So, hydrothermal treatment is economically preferable than alkaline digestion as a pretreatment method for ethanol production from rice straw.

Details	Sri Lanka	Japan	Unit
Rice straw generation	3.7 (2009)	8.5 (2009)	Million MT
Cost of straw	37.4	187 [2]	US $/t
Current annual production of ethanol from rice straw	0	96 [3]	kl/year
Gasoline demand	0.7 [4] (2007)	58.4 [5] (2010)	Million kl
Current ethanol potencial to satisfy the gasoline demand	0	0.000164384	%
Highest possible production of ethanol from locally produced rice straw (100%)	0.28	0.5	Million kl/year
Ethanol potencial if all the straw used for ethanol production	40	0.856164384	%
Availability of straw for ethanol production	50	4.6 [6]	%
Possible production of ethanol from available rice straw	0.14	0.03	Million kl/year
Possible ethanol potencial to replace gasoline with available rice straw	20	0.051369863	%

Potential of ethanol

Only 50% of rice straw generated in paddy fields is used as a fertilizer and other purposes in Sri Lanka. The remaining 50% has become a trouble for farmers as government doesn't allow open burning due to air pollution. So this available resource can produce around 0.14 million kl per year of ethanol which can satisfy 20% of total gasoline requirement.

Conclusions

Ethanol production from rice straw is a suitable technology for Sri Lanka as a solution for dependency on fossil fuels due to high availability and low cost of raw materials. Lesser the cost of rice straw shows lesser the production cost and higher the profit. Cost of rice straw has a big influence on ethanol production cost for the production process with alkaline digestion than the production process with hydrothermal treatment. Reusing of lignin rich residue as boiler fuel reduces ethanol production cost. To make profits from all the scenarios by selling ethanol for 1.2 $/l, the cost of the rice straw should not exceed 24 $/t. For both production methodologies in scenario 1 and 2, pretreatment process steps show highest percentage of contribution for environmental impacts. Reusing of lignin rich residue as boiler fuel is environmentally and economically beneficial than non-reusing methods. Hydrothermal treatment is economically and environmentally favorable than alkaline digestion. From all four scenarios, scenario 4 is most favorable considering economical and environmental benefits.

References

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