IJEEP

INTERNATIONAL JOURNAL OF ENERGY ECONOMICS AND POLICY

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2017, 7(4), 172-180.

Assessing the Viability of Growing *Agave Tequilana* as a Biofuel Feedstock in Queensland, Australia

Roshan Subedi[1], Delwar Akbar[2]*, Nanjappa Ashwath[3], John Rolfe[4], Azad Rahman[5]

[1]School of Business and Law, Central Queensland University, Australia, [2]School of Business and Law, Central Queensland University, Australia, [3]School of Health, Medical and Applied Sciences, Central Queensland University, Australia, [4]School of Business and Law, Central Queensland University, Australia, [5]School of Business and Law, Central Queensland University, Australia. *Email: d.akbar@cqu.edu.au

ABSTRACT

This study assessed farmer's perceptions about cultivating *Agave tequilana* for bio-ethanol production in Australia and its economic viability. This plant has been growing in Ayr, a trial site in Queensland, Australia. This study found both farmers and stakeholders are ready to accept *A. tequilana* as a potential biofuel crop because farmers can use their marginalised land, where they require less water and nutrients. Commercial farming of *A. tequilana* could be supported in Queensland by existing sugar mills, infrastructure and technologies to minimize the cost associated with transport and processing. An economic model has been developed with a sensitivity analysis to assess the net present value of bioethanol production over a 40 year period.

Keywords: *Agave Tequilana*, Bioethanol Production, Ayr, Queensland
JEL Classifications: Q42, Q48, R14

1. INTRODUCTION

Biofuels feedstocks can be sourced from diverse agricultural commodities such as sugarcane, corn, soybean, rapeseed, wheat, sweet sorghum and barley (O'Connell et al., 2007; Rajagopal et al., 2007), which are also primary food sources for human beings. As a consequence, biofuels produced from these sources have raised the "food versus fuel" debate. Currently, the biofuel industry is in search of biofuel feedstock that does not compete with human food supply and fertile land. *Agave tequilana* has been found to be one possibility, as it can grow on marginal lands in semi-arid and arid regions, with minimum fertilizer and irrigation, and hence it can be cultivated in soils not suited for crop plants (Chambers and Holtum, 2010; Davis et al., 2011; Nunez et al., 2011).

There are at least 200-300 *Agave* species worldwide, and 150 of these species can be found in Mexico alone (Nunez et al., 2011). *A. tequilana, Agave angustifolia* and *Agave esperrima* are the three dominant species of *Agave* that are cultivated in Mexico because of their high sugar content and low cellulose contents. Amongst the three species, *A. tequilana* is the only species used in the production of "Tequila" and *Agave* syrup in Mexico because of the high inulin (fructose) and carbohydrate concentration in the plant (Cedeño and Alvarez-Jacobs, 1999; Iñiguez-Covarrubias et al., 2001). *A. tequilana* is a source of at least 35 other commercially viable substances that are used in food and medicinal products. These include inulin and fructose, sugar syrup, pulp, paper and fibreboard textiles and rope; plastics and other commercial and industrial products (Burger, 2008).

With Australia's large land mass and government's support for biofuel production from non-food crops, feedstocks such as *A. tequilana* might play a key role in determining the success of the biofuel industry (Davis et al., 2011; Holtum et al., 2011; Martinez-Torres et al., 2011; Valenzuela, 2011; Yan et al., 2011), yet there is very limited information about biofuel production from *Agave* plants. This paper aims to find out whether the Australian farmers are interested in cultivating *A. tequilana* in Queensland along with an economic model to assess the feasibility of commercial production of biofuel (i.e., ethanol) from this plant.

Current *A. tequilana* is only growing in Ayr, Queensland as a trial site. The region has potential to expand *A. tequilana* as an alternative crop with minimum competition with existing crops by using marginal land where sugarcane cannot be grown. Current sugar producers and processors in the region might diversify their incomes by producing both sugar and agave. This region has similar climatic conditions as Jalisco, Mexico, where *A. tequilana* is traditionally cultivated for Tequila production. Also commercial bioethanol production cost can be minimized by using the existing transportation, storage and processing infrastructure used for the sugarcane industries in Queensland. As agave is growing only in Ayr, Queensland, this study has chosen this as the study area to collect primary data about farmers and stakeholders' perception of growing this plant as well as its cultivating and processing costs data.

The paper is organized as follows. A literature review of *A. tequilana*, on its origin, characteristics and development are provided in Section 2, along with its ethanol production potential in comparison with other feed stocks. Section 3 provides a description of the methods and techniques used to collect and analyses the data from the trial site. The Section 4 presents key findings about farmer's perceptions about farming *A. tequilana* to produce bioethanol in Ayr, Queensland followed by an economic analysis of commercial bioethanol production in Section 5. The paper concludes in Section 6 with a discussion on the key findings.

2. ORIGIN AND CHARACTERISTICS OF *A. TEQUILANA*

2.1. Origin and Evolution of *Agave*

A. tequilana is one of the most important cash crops in Mexico (Simpson et al., 2011) and 84% of the total *A. tequilana* production in Mexico occurred in the state of Jalisco (Nunez et al., 2011). Some domestication characteristics that support commercial cultivation of *Agave*, summarised by Colunga-GarciaMarin and Zizumbo-Villarreal (2007), Hodgson (1995) and Valenzuela (2011), can be characterized as: Large heads and well developed leaf base, more fibrous and gigantism, production of bulbils, rhizomes, and infertile seeds, lower reproductive capacity, short maturation time, leaves easy to cut with little caustic sap and fewer teeth and spines leading to reduced obstruction for operations. Because of the above features as well as its water use efficiency, drought tolerance, and high sugar and fibre content, *A. tequilana* has received worldwide attention as a potential feedstock for bioethanol production (Davis et al., 2011; Holtum et al., 2011; Valenzuela, 2011).

Agave species have not been commercially used for fuel production to date in Australia (Chambers and Holtum, 2010; Davis et al., 2011; Holtum et al., 2011). *Agave* is an economically viable source of biofuels in arid and semi-arid land in Mexico, and Great Karoo in South East Africa (Boguslavasky et al., 2007, Borland et al., 2009; Burger, 2008). Australia has been highlighted as a potential country to adopt *Agave* as a potential biofuels feedstock to produce ethanol (Chambers and Holtum, 2010; Davis et al., 2011; Holtum et al., 2011; Martinez-Torres et al., 2011; Valenzuela, 2011; Yan et al., 2011).

2.2. Ethanol Yield from *Agave* in Comparison with Other Feed Stocks

A. tequilana plants have a sugar content of 27% to 38% (Brix, a unit that expresses the sugar content of an aqueous solution), which is three times higher than that of sugarcane. Furthermore the Piña of *A. tequilana* weigh around 60-90 kg each. Table 1 shows the ethanol yield of *A. tequilana* under optimal condition relative to other feed stocks.

From Table 1 it can be seen that *Agave* has maximum yield of 86.4 tonnes per hectare (t/ha) that can produce 8,000 L of distilled ethanol annually. In comparison sugarcane has a yield of 70 t/ha and can produce 4,900 L of cellulose ethanol per hectare annually. The feed stocks mentioned in Table 1 are the major sources of food items for human consumption except *Agave*. Furthermore, unlike other biofuel crops which are important feed stocks of ethanol in Australia, *Agave* do not demand such quantities of fertilizers, and water, thus making this crop more attractive. Therefore, among all the feed stocks that are listed in the Table 1, *A. tequilana* is seen as the best feedstock to produce biofuel in Australia without competing with food crops.

2.3. *A. tequilana* Research and Field Trials in Australia

Until now, very few studies have been conducted on *A. tequilana* to produce biofuels in Australia.

A desktop and a feasibility studies were conducted by Holtum et al. (2011) and Chambers and Holtum (2010) using different sites across Queensland, especially in sugar farm districts around sugar mills to develop the full package of practices of *A. tequilana* for Australian growers. Childers, Rockhampton, Mackay, Ayr and Mareeba are some of the potential production areas for *A. tequilana* in Queensland, Australia (Chambers and Holtum, 2010). These sites were identified because of similar climatic conditions to that of Mexico as well as the availability of marginal land not suitable for food crops production, transportation and processing infrastructure.

Table 1: Comparing *Agave* ethanol yield with current biofuels feed stocks

Crop	Yield tonnes/ha	Conversion ratio to sugar/starch (%)	Sugar to ethanol conversion rate (L/tonne)	Overall ethanol yield kg/ha/year
*A. tequilana**	86.4	24	600	8,000
Sugar cane	70	12.5	70	4,900
Cassava	40	25	150	6,000
Corn	5	69	410	2,050
Wheat	4	66	390	1,560
Sweet sorghum	35	14	80	2,800

Source: Reproduced from Rao (1997) and Wang (2002), *Data for *A. tequilana* was sourced from Chambers and Holtum (2010), *Agave tequilana: A. tequilana*

Chambers and Holtum (2010) also found that although it takes about 5 years to achieve the first financial returns from *A. tequilana* but the yield from *A. tequilana* can be same or more than that of sugarcane over a same period of time. It should also be noted that *Agave* is less harvest intensive than any other biofuel feed stocks and thus saving time and cost to the farmers.

In Australia the first trial of *A. tequilana* was established in June 2009 in Ayr, Queensland. This site is located 5.6 km away from the Ayr's central business district near the Kalmia sugar mill. The aim of this trial was to determine the potential of *A. tequilana* to grow in Queensland with the view to using its biomass for ethanol production. In Australia *Agave* plant can be planted mechanically by 2 m row spacing to cultivate 5000 plants per hectare (Chambers and Holtum, 2010). The yields per hectare could range from 300 to 500 tonne as the weight of the plant may vary from to 120 kg from a low of 60 kg (Chambers and Holtum, 2010).

2.4. Climate and Land Suitability in Australia for Growing *Agave*

Agave species can grow in soils of poor quality with extreme drought and elevated temperatures, with an annual rainfall amount of 102-127 mm to achieve optimum growth (Davis et al., 2011). In Mexico, high production has also been observed with as little as 25-38 mm of annual rainfall (Kirby, 1963). Holtum et al. (2011) and Chambers and Holtum (2010) have identified suitable climates and rainfall patterns in Queensland, reporting that these conditions are similar to those encountered in Jalisco region of Mexico. The average rainfall in Queensland is between 800 and 1000 mm per annum with an average temperature of 30°C. With similar climatic condition and rainfall patterns, it is predicted that Queensland can be a potential state for the production of *A. tequilana*, especially for bioethanol production.

2.5. Potential Challenges of Growing *Agave* in Australia

The cost of commercial farming of *A. tequilana* in Australia has not been studied so far. Chambers and Holtum (2010) predicted some of the financial costs and developed a model based on the similarity of climatic condition areas of *A. tequilana* cultivation in Mexico to those of several regions in Queensland. In Australia, *Agave* can be grown and processed using the existing combination of sugar mill and winery infrastructure (Ausagave, 2011). The current planting, pruning, weeding and harvesting that are being used for sugarcane would have to be modified for *A. tequilana* as this species would grow up to 1.8 m tall and weigh about 60-120 kg per plant (Holtum et al., 2011). It can be harvested in 5 years as a fully matured plant, and the leaves can be harvested after 2-3 years once the leaves are big enough to be used as a feedstock (Chambers and Holtum, 2010).

3. METHODOLOGY

Primary data and information were collected from direct observation through farm visits, participant observation, questionnaire surveys (farmers) and stakeholder's interview. This study used a survey method to assess the farmer's perceptions about growing *A. tequilana* in Australia. Sugarcane farmers from Ayr, Queensland were only the primary participants in this face to face survey. A total of 51 sugarcane farmers were randomly surveyed in July/August 2012. The questionnaire was divided into three sections: Farmer's perception about living; farmer's perception about introducing *A. tequilana* to produce biofuels and socio-demographic characteristics of the farmers. In order to finalise the questionnaire, a pilot survey was also conducted with respondents.

A total of eight stakeholders including persons associated with the biofuels industry, government organization, farming organizations, academics and beneficiaries were also interviewed via telephone conversation. For the stakeholder interview, an open ended questionnaire was prepared. The stakeholders were asked to give their opinion on questions relating to "Assessing the viability of growing *A. tequilana* for biofuels production in Australia."

The survey data were then coded and analyzed to identify patterns in the responses. The data were validated by checking every fifth survey entered to verify accuracy of data entry. The data were transferred to Statistical Package for the Social Sciences to carry out further inferential testing. Secondary data were collected from archival documents and records such as scientific publications, Government Bureau of Statistics, state agencies and private organisations. Some cost related data on bioethanol production have been taken from published research outputs.

4. FINDINGS AND ANALYSIS

Land around Ayr is primarily used for sugarcane production and cattle grazing, with some smaller areas under tropical fruit and vegetable cultivation. This section presents the survey findings about farmer's perceptions about introducing *A. tequilana* in Ayr, Queensland and the later part of this section presents the findings from the stakeholder interviews.

4.1. Socio-demographic Characteristics

In 2012, Ayr had a population of approximately 8,500 people (Burdekin Shire Council, 2012). Agriculture is the highest employer in the Ayr region (21.8% of the total workforce) and cropping represents 96.7% of all agricultural production in the region, making it one of the agriculture dominated regions in Queensland (Burdekin Shire Council, 2012). Table 2 summarise the socio-demographics characteristics of the respondent of the survey.

It was revealed from the survey that on an average, the respondents have been farming sugarcane as a main crop for 35-40 years. Hence

Table 2: Socio-demographics characteristics of the surveyed respondents of Ayr, Queensland

Socio demographic characters	Statistics
Median age of the farmers	48
Median education of the farmers	Secondary
Median income of the farmers	$ 85,000
Average gender involved in farming	Male (100%)
Average number of persons in the family	4
Average number of persons involved in farming within family	2

the majority of the respondents were established farmers and the average size of farms owned by each respondent was 100-200 hectares. On an average, the cost of farming land per hectare in Ayr is between A$15,000 and A$20,000.

4.2. Farming Characteristics in Ayr, Queensland

As part of the survey, respondents were asked to provide details of the total land they owned and the total land owned for sugarcane only in Ayr, Queensland. This information was required to ascertain the amount of land that is currently being used for farming sugarcane and other crops, and the remainder of the land that has not been used (vacant land) is potential for farming of other crops which can be used for cultivating *A. tequilana*. It was found that 8,592 hectares of land was owned by 51 farmers, and 88% of their total owned land is currently being used for sugarcane farming and the rest 12% land are available for any other commercial farming. Farmers might have enough marginal land to commercially establish *A. tequilana* as an additional cash crop. It was also identified that the majority of farmers, about 84%, had been farming only sugarcane as the main cash crop with 8% of the farmers had been farming sugarcane and vegetables. Among the rest 6% had been farming sugarcane combined with cattle production, and the remaining had been farming sugarcane and tropical fruits.

4.3. Farmer's Perception about Producing Biofuel from Biomass in Australia

The survey captured respondents' view about biofuel production needs of Australia from biomass such as *Agave*, to increase Australia's renewable energy sources and their perception about spending resources by the government and private sectors to conduct more feasibility studies (Table 3). The majority (92%) of the respondents agreed that Australia should produce energy from biomass like *Agave*; however the remaining 6% did not have any opinion and 2% strongly disagreed with this statement (Table 3).

To support biofuel production, some of the farmers also mentioned that sugarcane could be used to make ethanol. Currently, molasses (a by-product) is being used to produce ethanol in some sugar mills. In the second part, respondents were asked if it is worthwhile to spend resources by government and private sectors to conduct a feasibility study to produce biofuel in Australia. As per the survey 84.3% of the farmers believed that it is important to invest resources to conduct a feasibility study to produce ethanol from *A. tequilana* in the region while the remaining believed that it is not important.

4.4. Farmer's Perception about Produce Biofuel from *Agave*

To establish a new crop requires some changes in the current plant production system such as land preparation, weed and nutrient management techniques, crop rotations, cover crops, improved genetics, optimum populations, stress management and sanitation (Martin and Collins, 2009). In this study, farmers were asked if they were aware of *A. tequilana* and its potential to produce biofuel prior to undertaking the survey. 67% of the respondents in Ayr did not know about *A. tequilana*. However, within the known respondents (33%), many of them did not know about the crop's potential to produce biofuel.

The relationship between the willingness to introduce *A. tequilana* against farmer's education and age group were tested using Chi-square (χ^2) test (Table 4). The null hypothesis in this case is that a relationship does not exist between the farmers who were aware of *A. tequilana* and interest in farming *A. tequilana* in their marginal land'. It can be concluded that with 50 degree of freedom, the value of the χ^2 statistic $\chi^2 = 10.559$ and $P = 0.014$, which is less than the table value (67.505) at α level = 0.05; so, we reject null hypothesis and can conclude that there is a valid relationship between the farmer's prior knowledge about the plant and its possible introduction as a new plan at their marginal land (Table 4).

4.4.1. Farmer's education and willingness to introducing A. tequilana

The null hypothesis in this case is "there is no relation between the education level of farmers and knowledge about introducing *Agave* in Ayr." It can be concluded that with the 50 valid cases, the value of the χ^2 is 12.84 and the $P = 0.380$. The χ^2 value is higher than the table value at α level = 0.05, so we accept the null hypothesis and there exist no relationship between education of the farmers and possibilities of introducing *A. tequilana* in to the Burdekin region (Table 4).

4.4.2. Age of farmers and willingness to introducing A. tequilana

The null hypothesis in this case is "there is no relationship between the age of the farmers and the knowledge about *A. tequilana* in the Burdekin region." It can be concluded, that with 50 valid cases,

Table 3: Farmers perception about investing in biofuel industries

Variables	Statistics				
Australia's need to produce energy from biomass (%)	Strongly agree	Agree		No opinion	Disagree
	53	39		6	2
Spending resources to undertake biofuel feasibility studies by government and private sector (%)	Very important	Important	Fairly important	Slightly important	Not important at all
	35	29	20	10	6

Table 4: Farmer's willingness to introduce *A. tequilana*, in Ayr, Queensland

Chi-square	Value	df	Asymptotic significant (2-sided)
Farmer's willingness to introduce *A. tequilana* in Ayr	10.559[a]	3	0.014
Farmer's education with introducing A. tequilana	12.849[a]	12	0.380
Age of farmers and introducing *A. tequilana*	20.793[a]	12	0.053

A. tequilana: Agave tequilana

the value of the χ^2 = 20.79 and the P = 0.053. χ^2 value is higher at α level = 0.05, so we accept the null hypothesis and conclude that no relationship between age of the farmers and possibilities of introducing *A. tequilana* in the Burdekin region.

In Australia, farmers will be the primary producers providing necessary raw materials to produce biofuel from *A. tequilana*. Therefore, farmers were asked to give their perception about farming *A. tequilana* as a biofuel crop in Ayr, Queensland. From the survey results, it is evident that 10% of the farmers could introduce *A. tequilana* without any delay, while more than half of the farmers, 54%, would prefer to wait until the final result from the first trial at Ayr, Queensland (Table 5).

Farmers were asked about growing *A. tequilana* in their own marginal land where sugarcane or other crops cannot be grown. From Table 5, it can be seen that 26% of the farmers answered they would consider farming *A. tequilana* if they had marginal land, 20% answered they may grow this crop. Likewise, 36% of the farmers answered that they need to wait until the final results from the first trial sites at Ayr are finalised, and the remaining 18% of the farmers were reluctant to introduce *A. tequilana* on their marginal land. Some of those farmers who had marginal land showed an interest to trial the crop on a small scale. However, most of the farmers prefer to wait for the results of the first trial at Ayr and want to see a solid business case from the investors before they proceed further into cultivating the crop commercially. The results from the table indicates that if the first trial outcomes shows positive findings, then there is a possibility of farmers switching from sugarcane to *A. tequilana*.

4.5. Factors Affecting Adoption of *Agave* as New Crop

Availability of resources is important for start-up and business growth. The survey captured four factors which determine the rate of the potential adoption of *Agave* as a biofuel crop in Australia. Farmers and stakeholders were asked to give their opinion on these factors which are summarised in Table 6.

Most Australian farmers grow crops that give quicker financial returns, within 6-24 months, such as in growing vegetables, grains and sugarcane. Therefore, in this study farmers were asked to give their opinion on how many years they can afford to wait for the first financial return from *Agave*, as it takes 5 years for the first harvest. From Table 6, 86.3% of the farmers responded that they can wait just 5 years, 2% responded 6 years, another 2% responded more than 8 years, however, 9.5% of the farmers did not give their opinion. However, one of the stakeholders highlighted that *Agave* is less harvest intensive than other feedstock when it comes to harvesting every year, which saves time and cost to the farmers. Stakeholders also mentioned that it might be good for farmers to utilise *Agave* as a rotation crop.

Farmers were asked about the minimum rate of return that they would expect at harvesting time to make this *Agave* economically competitive with other crops in the region. The results show that 43.3% of the farmers think they need 20-25% return at the end of harvesting period, 24.5% think that they need 15-20%, 22.4% think that they need 10-15%, 5.9% think that they need 5-10% and 3.9% think they need more than 20-25% return (Table 6). When the same question was put on to the stakeholders, they also concluded that, if farmers had to wait for at least 5 years to get the return, then they expect the higher return from the crop in comparison with other crops which are currently being cultivated in the region. When farmers were asked about the need for technical or professional advice required for *Agave* farming, 51% of the respondents strongly agreed they need support, 37.3% of the respondents just agree, and 11.8% of the farmers did not have any opinion (Table 6). Most stakeholders indicated that farmers who are interested to farm

Table 5: Farmers perception about introducing *Agave tequilana* in Ayr, Queensland

Variables	Statistics				
Introducing *A. tequilana* in Ayr, Queensland (%)	Can be introduced	Need to wait until first trial		Need to do more R and D	Not sure
	10	54		20	16
Introducing *A. tequilana* in marginal land (%)	Yes	May be	After first trial result	May not be	Not at all
	26	20	36	8	10

Table 6: Factors affecting adoption of *A. tequilana* in Australia

Factors	Statistics					
Years farmer can wait to get financial return (%)	5 year	6 year	7 year	8 year	9 year	10 year
	86	2	0	0	2	10
Expected rate of return from *A. tequilana* (%)	5-10	10-15	15-20	20-25	If more specify	
	6	22	25	43	4	
Need technical/professional advice to farm *A. tequilana* (%)	Strongly agree	Agree	No opinion	Disagree	Strongly disagree	
	51	37	11	0	0	
Preferred assistance from government (%)	Subsidies machinery	Subsidies fuel	Interest free loan	All the options	Other	Not required
	4	2	6	80	2	6

A. tequilana: Agave tequilana

Table 7: Derivation of assumed *Agave* ethanol revenue at Ayr, Queensland per hectare

Variable	Assumption	Source
Area of each section (hectares)	7400	
Plant density	5000 plants per hectare	Chambers and Holtum (2010)
Average weight of biomass (harvested)	80 kg/plant	Chambers and Holtum (2010)
Sugar contained	24%	Chambers and Holtum (2010)
Ethanol extraction efficiency	99% (base case)	Luo et al., 2009
Fermentable sugar per ha	95.04	5000×80/1000×24%×99%
Ethanol extraction	600 L/tonne of fermentable sugar	Chambers and Holtum (2010)
Total ethanol produce per ha of *Agave* harvested	57024/L	600×95.04

Table 8: Assumed capital cost of *Agave* ethanol factory in Ayr, Queensland

Capital costs	Predicted cost (Aus $)	Sources
Land and development cost (15,000 ha at $400 per ha)	$ 6 million	Farmers (Burdekin region)
Planting, pruning and harvesting equipment	$ 5 million	Cane farmers (Burdekin region)
Transport equipment	$ 3 million	Cane farmers (Burdekin region)
Mill (ethanol factory)	$ 90 million	Base case scenario
Buildings, storage and road	$ 5 million	Personal communication
Electricity connection	$ 4.5 million	Personal communication
Total fire protection/water supply	$ 2 million	Asia-Pacific Economic Cooperation Energy 2010
Total capital costs	115.5 million	

Agave need to be trained by the professionals on how to cultivate, prune, harvest and look after the plants.

5. ECONOMIC AND SENSITIVITY ANALYSIS OF BIOETHANOL PRODUCTION FROM *AGAVE*

The economic assessment of an *Agave* based bio-ethanol plant is essential to justify growing agave in Queensland, Australia because bio-ethanol is the main processed product of *Agave.* The financial costs and returns depend on several factors such as plant capacity, process technology, production rate and cost of raw materials, chemical costs, fixed capital cost, production costs, depreciation, interest rates, and market price of the ethanol. Net present value (NVP) of the project is a crucial decision rule whether the project would have economic viability. Apart from the fixed capital cost, every other costs are dependent on two factors: Total flow of raw material and ethanol price considering the depreciation and the interest are fixed. In this section a financial cost benefit analysis along with a sensitivity analysis is included to estimate the NVP of the project over a 40 years period. For convenience, a 5% discount rate is considered for the initial estimate and later a comparative study for different discount rates are included. The sensitivity analysis provides the potential revenue outcome with different sets of parameters.

The proposed economic model is constructed on the basis of several assumptions. The total land required for the project is 37,000 hectares, which is divided into 5 blocks with 7400 hectares each with an assumption of successive plantation over a 5 years period. As *Agave* plants need to be harvested in every 5 years, it is assumed that five blocks of land will ensure the continuous supply of raw materials to the ethanol plant over the life of the plant (i.e., 40 years considered in this model). The assumption for the expected ethanol production from the project is summarized in Table 7.

The fixed capital cost for the project includes the land acquisition and development cost for the factory, construction cost of the ethanol factory, and the facilities development cost. The assumption of the break-even capital costs are summarized in Table 8 which is considered as the base case for the economic model.

The total cost for producing *Agave taquilana* is collected from the Ayr first trial site which includes the associated cost of different activities throughout the 5 years to harvesting. The activities at different stage of *Agave* cultivation are land preparation, irrigation, plantation, fertilizer and chemicals, harvesting and transportation. The cost required in different years are dependent on the activities and summarized in Table 9. It was assumed that the land preparation cost and the irrigation costs of the 1st year of 2nd and subsequent cycles will be 50% less than the 1st year of the 1st cycle of cultivation.

Based on the collected data from the trial site the *Agave* production costs for each year has been calculated for the project over a total of 37,000 Hectares of land. The capital cost of developing the facilities of ethanol plant is assumed to be distributed on the 3rd, 4th and 5th year so that the facilities will be available from the first cultivation on 6th year of the project. Plant operating cost is assumed from a report of an existing ethanol production firm in USA (Hofstrand, 2017). The total amount of *Agave* (in tonne) and extracted ethanol for *Agave* is calculated as per the data collected from literature and trial site, which is given in Table 7. The ethanol price at mill gate is assumed on the basis of current ethanol price in world market and the base case of the ethanol price for the current study is 0.51 Australian dollar (AUD)/L. The average weight of the *Agave* plant is found to be 80 kg/plant in the first trial site. It is understandable that the weight of the *Agave* plant and the price of the ethanol in world market can fluctuate, hence the sensitivity analysis for the current study considered those two as the parameters of the analysis. The results of the sensitivity analysis is summarised in Table 10.

Table 9: Annual cost of producing *A. tequilana* in Australia (5000 plants ha-1)

Time frame	Cost/hectare AUD $				
	Cost based on average of 3 years and sugarcane farming				
	Year 1	Year 2	Year 3	Year 4	Year 5
Total per year (Aus $ ha-1) 1st cycle	15040.5	1633	3607	2843	3523
Total per year for second and subsequent cycles (Aus $ ha-1)	11137.25	1633	3607	2843	3523

A. tequilana: Agave tequilana

Table 10: Sensitivity analysis

Average weight of *Agave* plant (kg)	Price of ethanol					
	0.45	0.48	0.51	0.54	0.57	0.6
70	−916,907,395	−767,689,314	−618,471,234	−469,253,154	−320,035,073	−170,816,993
75	−797,135,956	−637,259,441	−477,382,926	−317,506,412	−157,629,897	2,246,618
80	−677,364,517	−506,829,568	−336,294,619	−165,759,670	4,775,279	175,310,228
85	−557,593,078	−376,399,694	−195,206,311	−14,012,928	167,180,455	348,373,839
90	−437,821,639	−245,969,821	−54,118,004	137,733,814	329,585,632	521,437,449

The sensitivity analysis results given in Table 10 indicate that the base case (with average plant weight 80 kg and ethanol price 0.51 AUD/L) of the project might not be profitable. The analysis suggests that only a higher ethanol price (0.6 AUD/L) can secure a positive NPV after 40 years completion of the project. As it was expected the profit of the project increases with the weightier *Agave* plant which is bit unlikely in view of the available data from the trial site Ayr.

A graphical representation of the analysis is given in Figure 1. The surface diagram makes an impression that the NPV is more sensitive to the *Agave* plant weight comparing to the ethanol price as the surface shows stiff inclination with heavier plants. Though, one has to remember that the scale of the graph is not same in every direction and it may be misinterpreted if not carefully studied. The graph also indicate the segments where positive NPV can be achieved in this project.

According to the current analysis with the 5% of discount rate the project will not be able to gain sufficient profit for the base case. On this note, an additional sensitivity analysis was executed with variable discount rates considering the average weight of the *Agave* plant remain constant at the base case which is 80 kg/plant. The results of the analysis is presented in Figure 2 which indicate that even with the 3% discount rate the project failed to gain a positive NPV with the current ethanol price. With a slight increase of ethanol price at 0.54 AUD/L, which is a feasible case, the project could potentially accumulate about 75 Million AUD in terms of NPV with a discount rate of 3%. The results also shows that event with higher price of ethanol the project will not get enough profit if 7% discount rate is applied.

The current sensitivity analysis suggests that the project of ethanol production from *Agave* plant is not profitable on the current base price and weight; however if either or both price and weight increase can turn this into a profitable operation with positive NPV (Figure 1). The price of the ethanol has pivotal impact on the NPV of the project and with the higher ethanol price and low discount rate this project still has some prospect to achieve potential profit. Queensland's weather is suitable for *Agave* plantation and for growing larger *Agave* plant which was reflected form the trial site data and larger *Agave* plant may also help generating positive NPV. In addition, current governmental subsidy, which is valid till 2021 can help produce economically feasible bioethanol production in the short run under each of sensitivity parameters considered in this model but it is not recommended for a long run scenario. However, this study did not consider the value of the by-products that can be produced from the bagasse of agave such as bagasse processing

Figure 1: Sensitivity analysis of net present value

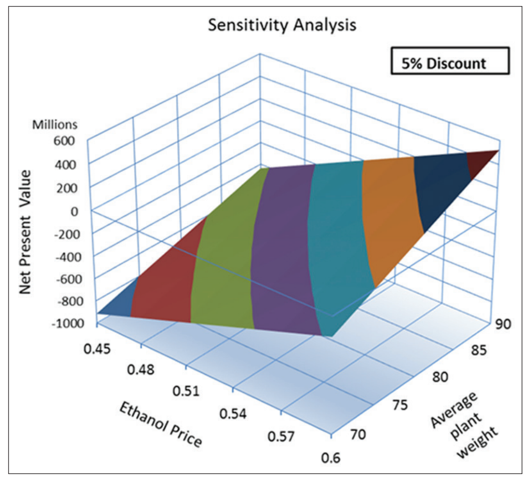
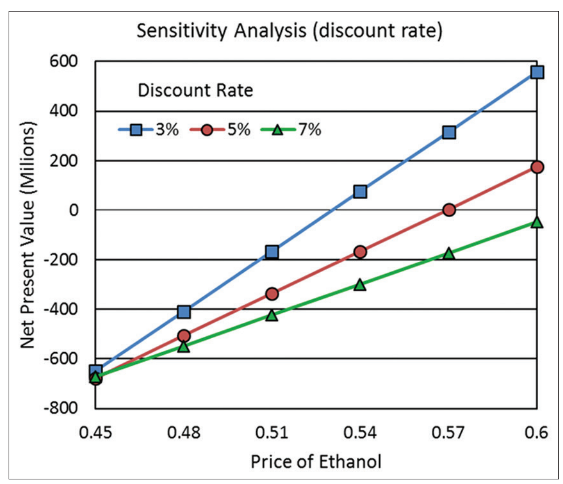


Figure 2: Net present value of the project with different discount rate



for second stage production of bioethanol and fibre, which was not within the scope of the study. However, adding these by-products to the current economic model may emerge the proposed plant as an economically feasible plant under the current base case scenario.

6. DISCUSSIONS AND CONCLUSIONS

This study assessed the viability of growing *A. tequilana* for bioethanol production in Australia and this is one of the pioneer studies in Australia's context. To date, no commercial *A. tequilana* derived ethanol factories exist in Australia or elsewhere to accurately calculate the cost of producing ethanol from *A. tequilana*.

In this study, although farmers and stakeholders were concerned about the location of trial site and the land availability, it appears that they are ready to accept *A. tequilana* as a potential biofuel crop. With the acceptance from both the farmers and the stakeholders, and considering Queensland having similar climate and rainfall patterns to that of Jelisco, Mexico where *Agave* is traditionally grown; it is concluded that *A. tequilana* can be a viable alternative biofuel crop in Australia. Given the limited arable land and water resources globally, the food versus fuel argument is gaining momentum where agriculture commodities have been used to produce biofuels to meet the current demand. *A. tequilana*, being a drought tolerant plant, could be a highly potential feedstock for ethanol production with minimum pressure on food production and water resources. Likewise, if the biofuels industry is established from *A. tequilana,* it will also create new employment from its economic value chain such as during *Agave* farming, processing in mills, distributing, retailing and other indirect jobs.

In Australia, commercial farming of *A. tequilana* can be supported by the existing sugar mills, infrastructures and technologies to minimize the cost associated with transport, farming and processing; however this has not been considered in the economic model presented in study. In sugarcane growing areas, this crop is also expected to act as a rotation crop that can stabilize farmer's income. Australian Government biofuel policy supports the use of non-food crops such as *A. tequilana* as bio-ethanol feed stocks. However, before trialling *A. tequilana* as a biofuel feedstock in Queensland, farmers would prefer to wait until the first trial outcomes are summarized from Ayr. A sensitivity analysis was conducted in this paper by developing an economic model that comprises all the costs related to *Agave* production and biofuel extraction from it. The results shows that the current base case of ethanol price and average size of the *Agave* plant do not lead to a positive NPV of the project. It is also revealed that with a lower discount rate and marginal increase of ethanol price could make the project cost-effective. Increasing the size of the *Agave* by means of fertilizer could be another option to increase the NPV as the *Agave* plant could be as heavier as 120 kg while the base case is only 80 kg.

REFERENCES

Ausagave. (2011), AUS *Agave*. Available from: http://www.ausagave.com.au. [Last viewed on 2013 Jan 02].

Boguslavasky, A., Barkhuysen, F., Timmer, E., Matsane, R. (2007), Establishing of *Agave americana* Industry in South Africa. Paper Presented to the 5th International Conference on New Crops, Southampton, UK, 19 April, 2012.

Borland, A., Griffiths, H., Hartwell, J., Smith, J. (2009), Exploiting the potential of plants with crassulacean acid metabolism for bioenergy production on marginal lands. Journal of Experimental Botany, 60, 2879-2896.

Burdekin Shire Council. (2012), The Burdekin Shire Community Plan 2012-2022. Available from: http://www.burdekin.qld.gov.au. [Last accessed on 2012 Aug 25].

Burger, A.K. (2008), Mexico and *Agave*: Moving from Tequila to Ethanol. Available from: http://www.renewableenergyworld.com/rea/news/article/2008/08/mexico-agaves-moving-fromtequila-to-ethanol-53265. [Last accessed on 2013 Feb 07].

Cedenño, C.M., Alvarez-Jacobs, J. (1999), Production of tequila from *Agave*: Historical influences and contemporary processes. In: Jacques, K., Lyons, T.P., Kelsall, D.R., editors. The Alcohol Textbook. 3rd ed. Notighman, UK: Nottingham University Press.

Chambers, D., Holtum, A.M. (2010), Feasibility of *Agave* as a Feedstock for Biofuel Production in Australia, RIRDC Publication No. 10/104. Available from: https://www.rirdc.infoservices.com.au/items/10-104. [Last accessed on 2013 May 02].

Colunga-Garcia, M.P., Zizumbo-Villarreal, D. (2007), Tequila and other *Agave* spirits from west central Mexico: Current germplasm diversity, conservation and origin. Biodiversity and Conservation, 6, 1653-1667.

Davis, S.C., Dohleman, F.G., Long, S.P. (2011), The global potential for *Agave* as a biofuel feedstock. GCB Bioenergy, 3(1), 68-78.

Hodgson, W.C. (1995), *Agave delamateri* (Agaveaceae) and its role in the subsistence patterns of pre-columbian cultures in Arizona. Haseltonia, 3, 130-140.

Hofstrand, D. (2017), Ag Decision Maker, D1-10 Ethanol Profitability, Monthly Profitability of Ethanol Production. Available from: http://www.extension.iastate.edu/agdm/refirst.html. [Last accessed on 2017 Feb 20].

Holtum, J.A.M., Chambers, D.O.N., Morgan, T., Tan, D.K.Y. (2011), *Agave* as a biofuel feedstock in Australia. GCB Bioenergy, 3(1), 58-67.

Iñiguez-Covarrubias, G., Díaz-Teres, R., Sanjuan-Dueñas, R., Anzaldo-Hernández, J., Rowell, R.M. (2001), Utilization of by-products from the tequila industry. Part 2: Potential value of *Agave tequilana* weber azul leaves. Bioresource Technology, 77(2), 101-108.

Kirby, R.H. (1963), Vegetable Fibres: Botany, Cultivation, and Utilization. London: Leonard Hill.

Martin, H., Collins, D. (2009), Starting an Organic Farm. Ministry of Food and Agriculture, Ontario. Available from: http://www.omafra.gov.on.ca/english/crops/facts/09-073.html. [Last accessed on 2013 Mar 22].

Martinez-Torres, J., Barahona-Perez, F., Lappe-Oliveras, P., Colunga-Garcia, M.P., Magdub-Mendez, A., Vergara-Yoisura, S., Larque-Saavedra, A. (2011), Ethanol production from two varieties of henequen (*Agave fourcroydes* Lem). GCB Bioenergy, 3(1), 37-42.

Nunez, H.M., Rodriguez, L.F., Khanna, M. (2011), *Agave* for tequila and biofuels: An economic assessment and potential opportunities. GCB Bioenergy, 3(1), 43-57.

Luo, L., Van Der Voet, E., Huppes, G. (2009), Life cycle assessment and life cycle costing of bioethanol from sugarcane in Brazil. Renewable and Sustainable Energy Reviews, 13(6-7), 1613-1619.

O'Connell, D., Batten, D., O'Connell, M., May, B., Raison, J., Keating, B., Beer, T., Braid, A., Haritos, V., Begley, C., Poole, M., Poulton, P., Graham, S., Dunlop, M., Grant, T., Campbell, P., Lamb, D. (2007), Biofuels in Australia-issues and Prospects, RIRDC Publication

No. 07/071. Rural Industries and Research and Development Corporation. Available from: https://www.rirdc.infoservices.com.au/downloads/07-070. [Last accessed on 2013 Mar 01].

Rajagopal, D., Sexton, S.E., Roland-Holst, D., Zilberman, D. (2007), Challenge of biofuel: Filling the tank without emptying the stomach? Environmental Research Letters, 2(4), 1-9.

Rao, P.J.M. (1997), Industrial Utilisation of Sugarcane and its Co-Product. New Delhi: Indian Commission of Sugar Industry Development.

Simpson, J., Martinez, H.A., Jazmin, A.J.M., Delgado, S.S., Sanchez, V.A., Cortes, R.C. (2011), Genomic resources and transcriptome mining in *Agave tequilana*. GCB Bioenergy, 3(1), 25-36.

Valenzuela, A.N.A. (2011), A new agenda for blue *Agave* landraces: Food, energy and tequila. GCB Bioenergy, 3(1), 15-24.

Wang, W. (2002), Cassava Production for Industrial Utilization in China-Present and Future Perspectives, Proceedings of the 7th Regional Cassava Workshop, Bangkok, Thailand.

Yan, X., Tan, D.K.Y., Inderwildi, O.R., Smith, J.A.C., King, D.A. (2011), Life cycle energy and greenhouse gas analysis for *Agave* derived bioethanol. Energy and Environmental Science, 4(9), 3110-3121.