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Department of Economics

Cost Benefit and Risk Analysis of Biofuel Production in Pakistan

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Master's thesis · 30 hec · Advanced level
Environmental Economics and Management – Master's Programme
Degree thesis No 767 · ISSN 1401-4084
Uppsala 2013

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Credits: 30 hec
Level: A2E
Course title: Degree Project in Economics
Course code: EX0537
Programme/Education: Environmental Economics and Management, Master's Programme
Faculty: Faculty of Natural Resources and Agricultural Sciences

Place of publication: Uppsala
Year of publication: 2013
Name of Series: Degree project/SLU, Department of Economics
No: 767
ISSN 1401-4084
Online publication: http://stud.epsilon.slu.se

Key words: biofuel, cost benefit analysis, Pakistan, feedstock, Jatropha, Corn, Switchgrass, Sugarcane

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Acknowledgements

After thanking Allah Almighty, I would like to acknowledge all those who helped me to complete this thesis.

Firstly, I would like to express my gratitude to my supervisor, Prof. Ing-Marie Gren, for her continuous guidance, useful support and assistance during the entire period of project. I will never forget the kind suggestions and helpful tips during meetings and discussions. Thank you once again!

Secondly, I am grateful to Prof. Katarina Elofsson, my evaluator, for her valuable comments. Your constructive comments encouraged me to critically revise my thesis before submission.

Thirdly, I express many thanks to all my great professors both at SLU and Uppsala University. Thank you very much for teaching such a valuable subject. Thanks to all my Pakistani and international friends, and classmates for their support during my stay in Sweden. Love you all.

I would love to pass special thanks to my husband Muhammad Munir for his continuous support and guidance. Thanks for listening all my issues. This thesis would not have been completed without your precious love and care. Lots of love and thanks to my sweet little doll Haniya (who was born during my thesis project) for being calm and not bothering me much for the whole duration.

Also, special thanks go to my parents and brothers for always supporting me with your humble prayers and encouragement. May you live long and always be happy.

Abstract

To meet rising demand of energy, bioenergy is getting great attention in an energy-deficient country; Pakistan. In this respect, food and non-food feedstocks are being examined economically, environmentally and in terms of energy balance. Work in this thesis deals with supply side analysis of liquid bioenergy options in Pakistan. The main purpose is to measure net economic returns by computing costs and benefits of 1st and 2nd generation biofuels production from the perspectives of private producer. For this purpose, four types of feedstocks i.e. jatropha, switchgrass, corn and sugarcane were selected in accordance with the specific agrarian facts, soil properties and climatic conditions of Pakistan. Due to constrain of unavailability of reliable data for efficient conversion standards in Pakistan, data requirements of biofuel production procedures were adapted from neighbouring and efficiently producing countries. Standard cost-benefit technique was applied to analyze and compare net returns of all the four feedstock-based biofuels in monetary terms. For risk assessment in all biofuels production, Monte Carlo simulation was applied. The results indicated positive net returns only for jatropha. Hence all other feedstocks possessed negative profits and shown economic inefficiency. The major reason was found to be the high feedstock price. A sensitivity analysis was conducted to check the break-even price of feedstock. It indicated that 8%, 30% and 44% decrease in prices of switchgrass, cane molasses and corn, respectively, could make net returns for biofuels positive. Furthermore, a risk analysis was conducted to evaluate the level of risk for each fuel source. The results indicated that there is a trade-off between net returns and risk; high net profits possess high level of risk. Choices of production level in the case of uncertainty vary depending upon the requirement of different criteria. In conclusion, this study favours the production of jatropha biodiesel.

Abbreviations

AEDB	Alternative energy development board
B10	10% blend of biodiesel with mineral-diesel
CBA	Cost benefit analysis
CO	Carbon mono oxide
CO_2	Carbon dioxide
ER	Exchange rate
FGF	First generation biofuels
GHG	Green house gas
Ha	Hectare
kl	Kiloliter
MJ	Maga joul
NEV	Net energy values
NSB	Net social returns
PKR	Pakistani rupee
PPP	Purchasing power parity
PSO	Pakistan state oil
REP	Renewable energy policy
RNEV	Renewable net energy value
SGF	Second generation biofuels
SO_2	Sulphur dioxide
USD	United States Dollar

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1. Introduction

Biofuels[1] are renewable, biologically degradable, non-toxic and environmental friendly fuels. It is strongly believed that the biofuels are favourable substitutes for fossil fuel (Wang *et al.,* 2011), and that the production and consumption have potential to provide a simultaneous pathway to rural development, employment opportunities, reduced emissions and less dependency on mineral fuels (Schmer *et al.,* 2008; Wang *et al.,* 2011). Furthermore, biofuels are considered a promising source to solve a series of interconnected international problems such as increasing energy demand, high fossil fuel prices, depletion of fuel reserves and environmental degradation.

Extraction and usage of these fuels have been rising quickly in recent years. According to an estimate made by Carriquiry *et al.* (2011), biofuel production has increased about three folds in case of ethanol, which increased from 31300 million litres in 2005 to 85600 million litres in 2010, globally. Moreover, the production of biodiesel has become more than four times higher than it was in 2005.

Biofuels are commonly divided into two categories: first generation biofuels (FGF) and second generation biofuels (SGF). FGFs are made from edible feedstocks, which contain starch as the main component such as sugarcane, sorghum, seed crops etc. (Carriquiry *et al.,* 2011). Currently, these are the most favourable sources of alternative energy and enjoy low cost production technology (Kline *et al.,* 2008). On the other hand, some major concerns are associated with FGF such as changes in land use, impacts on biodiversity, rising competition and prices of feed and food crops, which restrict their majestic production and consumption.

Another type of biofuels, called second generation biofuels (SGF), are extracted from lingo-cellulosic and non-food agricultural feedstocks. Cellulosic feedstock contains agricultural, animal and forest residuals and energy crops such as perennial forage crops, e.g., switch grass, miscanthus and woody fast growing trees, e.g., poplar, eucalyptus and willow. Biodiesel feedstocks are microalgae and oily seeds of jatropha, canola and jojoba (Carriquiry *et al.,* 2011). Most of the feedstocks for SGF are available in abundant quantity and are considered underutilized biological sources on the earth (Naik *et al.,* 2010). Production of these fuels has been successfully launched. However, being techno-economically infeasible, SGFs need immense efforts to get access to ripe technology (Eggert *et al.,* 2011). Low-cost conversion technologies for SGF are presently progressing on with the hope of cellulosic and non-food crops to be the major raw material in biofuel production (Kline *et al.,* 2008). It is expected that these biofuels will be helpful in reducing burden from food crops, supplying cheap and plentiful feedstock (Naik *et al*., 2010), shrinking CO_2 emissions and providing an additional source of income by removing the waste (Khan *et al.,* 2011).

For the establishment of biofuel production devices in Pakistan, technical knowhow and estimating economic costs and benefits of production are the primary steps. In addition, industrial level scaling up of biofuels, especially second generation biofuels is encircled by some very decisive concerns and issues, such as, can the prices of biofuels cover the cost of

[1] "The term biofuel is referred to as solid (bio-char), liquid (ethanol, vegetable oil and biodiesel) or gaseous (biogas, biosyngas and biohydrogen) fuels that are predominantly produced from biomass. The biggest difference between biofuels and petroleum feedstocks is oxygen content." By Demirbas (2009).

production of biofuels? How the cost of manufacturing SGFs varies compared to first generation? Are SGFs competitive with fossil fuels and FGFs?

On the other hand, biofuels production is prone to risk and uncertainly as that of many other agricultural-industrial products. Feedstock price and quantity, labour availability, wages, supply of utilities and prices of final product (biofuels) can be uncertain. As biofuel production is based on agricultural products, uncertainty exists in the quantity supplied and prices of a major component of biofuel; feedstock. Prices of biofuels, however, are thought more stable as compared to prices of fossil fuels. This is because, in most of the cases, biofuels are produced domestically and the price of biofuel depends on the agricultural feedstock, transportation, conversion to fuel and technological level. In this regard, currency risk, international market power and scarcity of reserves are not so important (Pauli and Nese, 2003). Risk in profit also depends on prices of all inputs and outputs as well as on the supplied quantity of raw material. There is a need to search out the factors of risk and uncertainty in production profits of biofuels in the specific setting of a country and crops.

Pakistan possesses favourable geographical position, geological features and diverse nature of climate, which are suitable for providing the raw agricultural material for biofuels production. Therefore, there lies a vast potential for such type of fuels. The Alternative Energy Development Board (AEDB) in Pakistan is enhancing tools (tax-free imports and price regulation) to encourage private investors to take part in production of biofuels. Moreover, assets and resources are gradually being shifted from public to private sector by the present government (Privatization Commission, PC, 2010) in order to optimise their profitability. These facts necessitate the analysis of cost and benefits of biofuel production with private producers' perspectives.

Many economic studies have estimated cost of production of biofuels (Kukrika, 2008; Zaman *et al.,* 2011; Sing-Min and Han, 2008; Carriquiry *et al.,* 2011) and made a comparison among biofuels produced by different sources (Pimentel and Patzek, 2005; Chakrabarti *et al.,* 2011). A comprehensive cost and benefit analysis of biofuels was carried out by Bell *et al.* (2011). Several studies are performed internationally; however, few of them have dealt with biofuels in Pakistan. The current available information has ascertained only private cost of biofuels production (Zaman *et al.,* 2011; Chakrabarti *et al.,* 2011). Net return analysis for biofuels and their risks have not been calculated in Pakistan.

The purpose of this thesis is to calculate and compare costs and benefits of first and second generation biofuels in Pakistan, and to evaluate their risks in profits. Representative for FGF (i.e. corn) and SGF (i.e. sugarcane, switchgrass, and jatropha) were chosen to compare their competitiveness. Since switchgrass, corn, and sugarcane are commonly being used for ethanol production whereas jatropha is being used for biodiesel production. Efforts were made to compare endpoint products for their suitability. Standard cost benefit approach (as given by Boardman *et al.* 2006) is applied to demonstrate net profits. Portfolio analysis is used to compute risk associated with all the biofuel types, where Monte Carlo simulation is applied for data retrieval. Only producers' production costs are calculated and not the benefits from replacing fossil fuel, such as environmental improvement and energy security. One prominent reason is that the purpose of the thesis is to compare different biofuel types, all of which create the same benefits associated with environmental improvements and energy security by replacing fossil fuel. Another reason is the difficulty of assessing these benefits in monetary terms. The results from the thesis thus give a priority order of the included biofuels; for given positive external effects the ranking is based on private net return and risk.

Different sections in this thesis are organized as follows: section 2 provides the necessary information regarding progress in biofuels research in Pakistan and briefly describes the country's biofuel promotion policy. Section 3 discusses previously conducted research in the field of biofuels, on both national and international levels. Theoretical implications of the cost benefit model are provided in section 4. Section 5 describes the source and collection of the data. The next section (6) focuses on the empirical study of the project and comprehensively describes the results. The analysed results, subsequent discussion and conclusions are provided in the final section 7.

2. Information about biofuels in Pakistan

Potentials and prospects of biofuel production in Pakistan are discussed in this section. Furthermore, the biofuel promotion policy of Pakistan is also briefly described.

2.1. Potential of biofuels in Pakistan

Pakistan is an agricultural economy and is situated in Southeast Asia. It possesses good geographical location, favourable climate and geological features for agriculture. A large proportion of the population is directly or indirectly engaged in agriculture. This sector provides livelihood to 45% of the population and is a main source of raw material for agro-based industry (Farooq, 2011).

Major crops in Pakistan include cotton, wheat, sugarcane, rice, maize, vegetables, fruits, and oil seeds. A map of Pakistan, reflecting land use categories, is presented in **Fig. 1** and the amount of land under different uses is provided in **Table 1**. The area under agriculture use is 21.73 million hectares according to soil survey of Pakistan (Khan and Dessouky, 2009). About 28.5 million hectares land is unproductive due to various reasons including high underground water level, saline soil, unfavourable temperature and scarcity of irrigational water at some locations.

As Pakistan is an agricultural state, there exists vast potential to promote bio-energy. Besides this, enormous availability of wasteland (28.5 million hectares as depicted in **Table 1**) provides an encouraging point to acquire energy from the potential plants and crops that can be grown on marginal land, which are included in second generation biofuels (SGF). The climate and soil properties of Pakistan also support the growth of a wide variety of conventional, non-conventional, industrial and wild oil-yielding crops[2] (Khan and Dessouky, 2009).

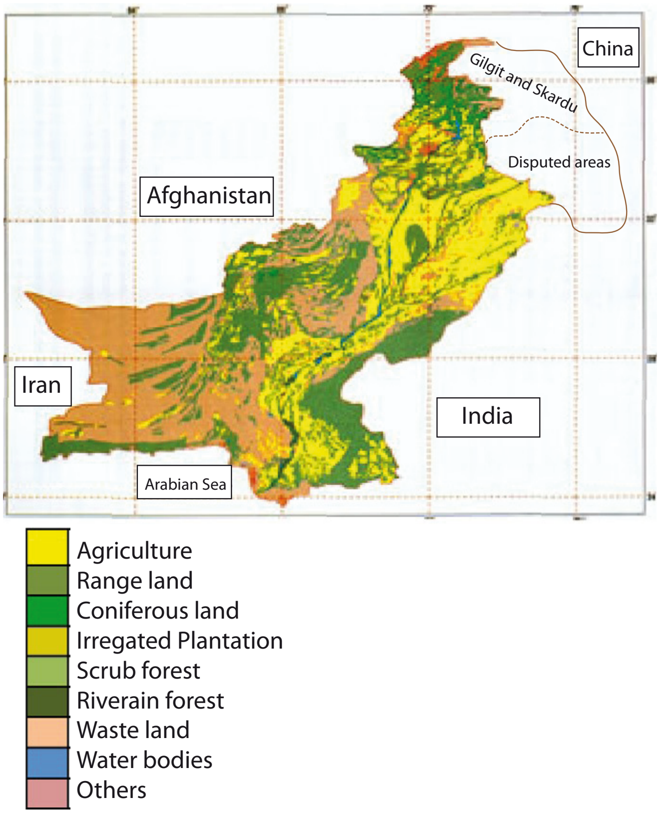


Fig. 1: Pakistan soil map[3]

[2]Conventional oil seeds include rapeseeds, ground-nuts and sesame and rocket seeds. Non-conventional seeds consist of sunflower, soybean and safflower, whereas industrial oil seeds are linseed, caster beans and cottonseeds. Wild crops consist of pongame tree, olive, hemp, oat, milk thistle, and carthamus seeds.
[3]Source: Khan and Dessouky, 2009.

Table 1: Land use categories of Pakistan[4]

No.	Land use type	Area (1000 ha)
1	Agriculture	21733
2	Rangelands	25475
3	Forests	2388
4	Irrigated plantation	80
5	Waste land including area under ice and snow	28501
6	Water bodies (rivers only)	1274
7	Others	159

On the other hand, there are several kind of materials produced as by-products, which can effectively be used as raw material for biofuels production. One such example is molasses, a by-product generated during sugar milling. According to the Pakistan Sugar Mills Association (Sep 5, 2012), 2 million tons of molasses is being produced from the sugarcane milling per annum. This molasses is estimated to yield 457.6 million litres of ethanol per year, at the rate of 4kg molasses to 1 litre ethanol (**Fig. 2**). **Figure 2** further shows the annual production of cane and beet molasses and estimated ethanol quantity, which can be generated from molasses. Although the entire molasses is not consumed in distilleries for ethanol production yet some part of it is also exported in raw format.

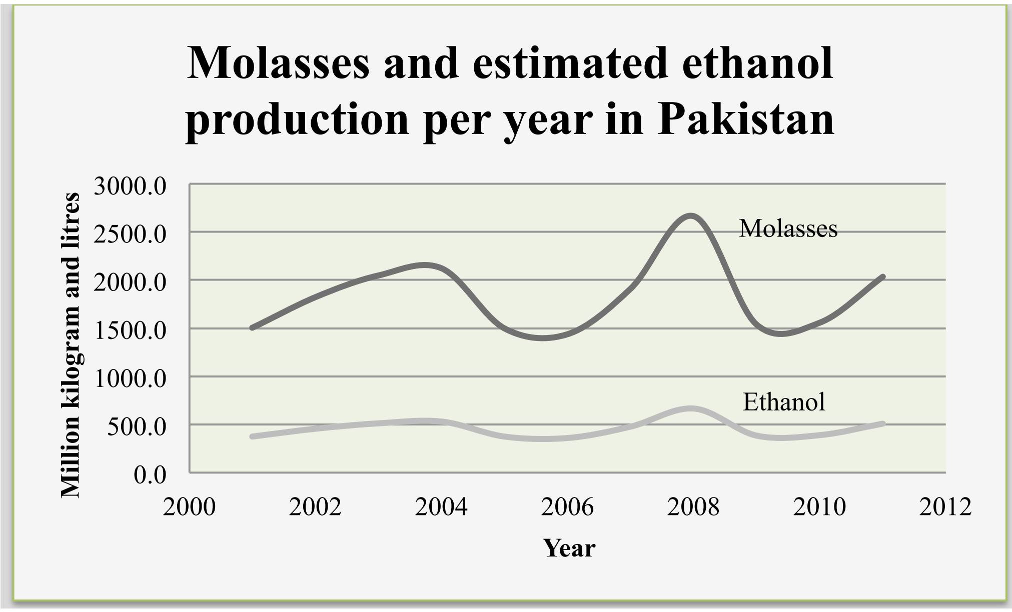


Fig. 2: Molasses and estimated ethanol production per year in Pakistan[5]

2.2. Biofuel promotion policy

Pakistani governmental agencies are keen to support projects dealing with alternative fuels. An example of practical devotion is the "Biodiesel Policy Recommendation" by Alternative Energy Development Board (given in the box below). According to this policy, the target is to achieve B5 (5% blending of biodiesel with fossil diesel) by the year 2015 and gradually enhance the blending standard to B10 by 2025. The Oil and Gas Regulation Authority (OGRA) of Pakistan will regulate prices of various blends of biodiesel and all the inputs and

[4] Source: Khan and Dessouky, 2009.
[5] Source: Pakistan Sugar Mills Association (http://www.psmacentre.com)

final products of biofuels will be subsidised by exemptions from custom duty, income tax and sales tax. As a consequence of these recommendations, a biodiesel refinery has been built at Karachi, which is capable of processing 18000 tons of biofuels per year (Shoaib, 2012).

In the private sector, the Pakistan State Oil (PSO) and Pakistan Agricultural Research Council (PARC) have launched a joint experimental project for jatropha plantation and oil extraction near Karachi, in the southwest of Pakistan. This project has proved very successful and has paved the way towards extended biodiesel production from wild plants (PSO, 2008). The PSO has started sale of E10 (10%+90% blend of ethanol and gasoline) from 1st Jan 2010.

Additionally, leading universities of the country are actively engaged in developing economical and environmentally efficient biofuels. A review for some of these studies is also provided in the next chapter.

Bio Diesel Policy Recommendations[6]

The Economic Coordination Committee (ECC) of the Cabinet considered the summary dated 14th February 2008, submitted by Ministry of Water & Power on “Policy Recommendations for Use of Biodiesel as an Alternative Fuel” and approved, in-principle, the following proposals contained in Para 4 of the Summary:

i). Ministry of Water & Power in coordination with AEDB shall be the apex coordinating and facilitating body for the National Bio-Diesel Programme.

ii). Gradual introduction of bio-diesel fuel blends with petroleum diesel so as to achieve a minimum share of 5% by volume of the total Diesel consumption in the country by the year 2015 and 10% by 2025.

iii). Oil Marketing Companies (OMCs) to purchase Bio-Diesel (B-100) from Bio-Diesel manufacturers; and sell this Bio-Diesel blended with Petroleum Diesel (starting with B-5) at their points of sale.

iv). Ministry of Petroleum & Natural Resources shall come up with the fuel quality standards for B-100 and blends up to B-20.

v). OGRA shall regulate the pricing mechanism of various blends of Bio-Diesel (B-5, B-10 etc.) and ensure its cost-competitiveness with Petroleum Diesel.

vi). The Government shall provide buy back guarantees to Biodiesel producers at a price determined by OGRA, by making it mandatory for public sector vehicles running on diesel to use Biodiesel.

vii). All imported plant, machinery, equipment and specific items used in the production of Biodiesel shall be exempted from Customs Duty, Income Tax and Sales Tax.

viii). Pilot project would be scaled up after success.

[6] Source: AEDB, 2011.

3. Literature Review

A brief review of previously performed research dealing with the net revenue (benefits or/and costs) estimates of biofuels is provided in this section. The purpose is to compare and examine the costs and/or benefits of a variety of feedstocks, in different regions of the world. Keeping in view the aims of this project, the review is provided for two main categories: biodiesel and ethanol.

3.1. Biodiesel

Chakrabarti *et al.* (2011) have analyzed the environmental and engine performance as well as economic costs of production of taramira (*Eruca sativa*) biodiesel and have compared its B10 blend with the properties of jatropha, caster and canola-based B10 biodiesels. The study was conducted on a minor scale and concluded that B10 blend of jatropha biodiesel yielded minimum emissions of SO_2 and CO_2 and had the lowest oxygen contents, whereas taramira emitted the lowest level of CO_2. It was revealed that taramira had poor engine performance, probably due to the low calorific values. On the other hand, feedstock production and conversion costs (estimated at current local market prices) of taramira were extremely high as compared to jatropha and caster which were 3.044, 1.039 and 1.78 USD/litre, respectively. The study suggested jatropha as the most cost effective feedstock among tested sources.

Zaman *et al.* (2010) evaluated the national and international experiences aiming at assessing the potential of jatropha production in Pakistan. In this regard, an economic benefit-cost analysis of jatropha was made based on types of soil and climatic conditions. Potential crop inferences were adopted from India. The properties of jatropha and other oil seeds were then compared in terms of oil yield, crop production and gross returns under low, medium and high yield scenarios. Projection of future (until 2030) edible oil consumption, yield and trade illustrate a production gap of 3.4 million tons in 2030, which is currently 1.86 million tons. Comparative analysis showed priority of edible oil seeds e.g. canola and sunflower in crops per year, oil contents, returns and price. Economic projection of jatropha generated gross returns of 185.91-697.51 USD[7]/ha. The variation in returns is because of poor soil with rain fed farming and fertile soil under irrigation. The analysis ended up with the conclusion of more feasibility of edible oils as compared to jatropha and recommended to tackle and carefully address the key issues of food security, cost efficiency and irrigational problems before implementation of jatropha project.

Wang *et al.* (2011) examined the economic, energy and environmental performance of jatropha produced on marginal lands in China, and evaluated the qualities of jatropha oil (JCL) blending with diesel and jatropha methyl ester (JME). For the purpose, a life cycle assessment was conducted using data collected through field surveys and from secondary sources such as energy yearbooks and databases about emissions. Full chain financial analysis revealed the economic infeasibility of jatropha biodiesel due to the higher proportion of costs going to feedstock cultivation and then a large amount of finance needed as fixed capital. Financial net present value also depicted that costs of JME are higher than JCL. The financial net present value for JCL and JME was estimated at 221.15 and 219.55[8] USD/ha, respectively. Furthermore, the green house gases (GHG) balance showed positive

[7] 1USD = 35.77PKR (for 2011, based on purchasing power parity)
[8] The original estimates were converted from Chinese Yuan to United States Dollar for the purpose of making comparison. 1USD=6.24 CHY as of 2011 (www.xe.com)

environmental performance for these two products, which emitted equally less CO_2, about 7.34 kg for JCL and 8.04 kg for JME. The energy balance of JCL and JME showed heating value of 1.57 and 1.47, respectively, which was feasible in terms of energy as these values were greater than one. Furthermore, an analysis to check how sensitive these two products are, against changes in parameters related to economic, energy and environmental circumstances, were also performed. Cost performance assessed by the study could substantially change the final results with the improvement in technology and soil quality.

Kukrika (2008) assessed the impacts of biofuels on the rural poor as well as briefly analyzed the industry and company level concerns about jatropha cultivation and biodiesel extraction in India. Annual costs of jatropha cultivation and conversion to biodiesel were estimated by surveys and interviews with farmers and industry owners. The study revealed high upfront costs, which diminish over time and after the period of 10 years constant costs of jatropha biodiesel were accounted per annum. The total cost of biodiesel was calculated to be 1.32 USD[9]/ litre in the 4th year which became 0.57 USD/litre in 10th year after gradual decrease. The costs were then compared to average petro diesel price, which resulted in a negative difference for 4th and 5th year but turned positive later on. Cost difference was estimated at 10% of total cost on average.

Sang-Min and Han (2008) examined economic feasibility of biodiesel manufacturing and their development trends in Korea. They focused on the study of two types of feedstocks; rape and soybean for biodiesel production and conducted economic feasibility using the benefit-cost approach. Rape was assumed to be cultivated by crop rotation with barley and soybean at fallow farms of set-aside land. By taking direct, indirect and environmental costs and benefits into account, the study concluded the economic feasibility of rape and soybean biodiesel in Korea. Net profits are 1108.16 and –30.27 USD[10]/kilolitre (kl) from rape cultivated as double cropping and on fallow land, respectively. For soybean obtained from normal land, net returns were recorded –347.67 USD/kl. Soybean that was grown on marginal land yielded net profits of 475.19 USD/kl. Thus, the study explicitily concluded the suitability of rape seed if grown as double cropping and of barley if cultivated on marginal land. However, it was recommended by the results of the study that government support and technological development should be continued to achieve minimum cost standards in feedstock cultivation.

3.2. Bio-ethanol

Carriquiry *et al.* (2011) reviewed the economic costs and benefits of biofuels production from various sources of second generation biofuels such as agricultural and forest residues, perennial and woody energy crops, jatropha, algae etc. The study combined and compared the production and conversion costs estimated by other researchers and concluded that whilst these fuels can significantly contribute to the energy sector, hence, cost is the foremost obstacle in their large-scale production. It came up with the general conclusion that ethanol extraction costs were two to three times greater than gasoline price whereas biodiesel production costs were seven times higher than petro diesel. The share of feedstock cost was lower (30-50%) in second generation biofuels as compared to first generation biofuels. The

[9] The original estimates were converted from Indian Rupee to United States Dollar.1 USD= 52.8 INR as of 2011 (www.xe.com)
[10] The original estimates were converted from Korean Won to United States Dollar. 1 USD= 1090.1 KRW as of 2011 (www.xe.com)

study recommended the distinction of policy interventions for both types of biofuel (first and second generation) to promote second generation biofuels.

Pimentel and Patzek (2005) performed a detailed and comprehensive energy input-output analysis and cost of production for variety of biofuels (switchgrass, corn, wood, sunflower and soybean) under the agricultural and fuel extraction setting of United States. The main conclusion of the study was that input fossil fuel energy requirement to produce biofuel was higher than net energy generated by biofuel. The reason stated for high input energy need is the removal of 92% water from ethanol-water mixture (8%+92%) resulted from conversion. For biodiesel, due to low oil contents of seeds, soybean and sunflower needed 27% and 118% more energy as input per unit of biodiesel produced. Per litre cost of production were estimated 0.45, 0.54, 0.58, 1.2, 1.6 USD for corn, switchgrass, wood cellulose, soybean and sunflower, respectively.

Aravindhakshan *et al.* (2010) evaluated the switchgrass and miscanthus. They analysed the economic performance of the species, yield per hectare and tax requirement for feedstocks based biofuels. In this regard, yield and energy estimates were obtained by field experiments under two standards: harvesting once and twice a year. The results indicated that on average miscanthus produced more biomass with two harvests per year, which were 12.39 and 13.04 tonne/ha/yr for single to double harvest, respectively. For switchgrass, mean biomass yield was high with one harvest, which was 15.87tonne/ha/yr and 15.42tonne/ha/yr for two harvests per year. The total cost of switchgrass production was 43USD/tonne and USD51/tonne for miscanthus. However, Carriquiry *et al.* (2011) have further evaluated ethanol costs for switchgrass and miscanthus, which were 0.144 and 0.169 USD/litre, respectively.

Bell *et al.* (2011) reviewed the costs associated with biofuels, and performed a cost benefit analysis of biofuels, realizing the need of promoting biofuel manufacturing policy and short term goals of biofuel program in Thailand. In this regard, attempts were made to measure all possible production, social and environmental costs and benefits, and evaluated in monetary terms. The impact on the whole production chain e.g. farmers, mills/refineries and local biofuel industry was taken into account. Economically, biofuel production was concluded to be infeasible as the cost of production (317 million USD) exceeded the cost of equivalent quantity of imported petroleum in Thailand. The net costs of bio-ethanol and biodiesel were estimated at 285 million USD, including benefits generated from savings from GHG, costs of ground level ozone formation and expenditures made by government on infrastructure and policy support.

Feasibility assessment and energy input-output evaluation of a wide range of biofuel production from various feedstocks were performed in numerous studies (Anwar *et al.,* 2010; Khatiwada and Silveira, 2009; Pimentel and Patzek, 2005; Pleanjai and Gheewala, 2009; Rashid *et al.,* 2009). On the other hand, economic costs and benefits in monetary terms, especially in the framework of developing countries, were analyzed in few research papers. However, the cost of biofuel production in monetary terms is up-to-date in biofuel efficient producer countries e.g. United States of America, Brazil and in some emerging economies e.g. India, Thailand.

In all the studies reviewed in this section, cost of production of biofuel varies in accordance with the type of feedstock, technological level and region specified infrastructure. Overall, the cost of production of biodiesel is 0.92-3.04 USD/litre and ethanol costs vary between 0.144 to 0.58 USD/litre.

For risk assessment and uncertainty, few of the research studies discussed the risk of biofuels in terms of shortage of feedstock and fuel supply, threats to food and the environment and abundance of invasive species e.g. Lonsdale and FitzGibbon (2011) and DiTomaso *et al.,* (2007). While discussing weakness and drawbacks of Indian biofuel policy, Rajagopal (2007), in his review, emphasised the need to maximize net benefits adjusted to risk in biofuel production. Besides these studies, reports that take risk and uncertainty into account in terms of biofuel are scarce.

Taken together, all the above-mentioned studies have provided foundations to plan the analysis aimed in this project. All studies except Bell *et al.* (2011) and Zaman *et al.* (2011) measured only cost estimates. The cost of biofuel production was then compared to petro fuel in monetary or/and energy terms (Pimentel and Patzek, 2005; Carriquiry *et al.* 2011; Kukrika, 2008). Notably, the net returns of biofuels, based on different feedstock, and risk in production remains to be investigated in Pakistan. Therefore, this study was designed to estimate the cost of biofuels (biodiesel and ethanol) and to compare them with their respective prices. Moreover, it was aimed to assess the profit risks for biofuel production.

4. Theoretical framework

In order to assess the net profit and risk of biofuels in Pakistan, standard technique of cost and benefit analysis (CBA) was applied. This section describes the theoretical framework of CBA and the deterministic model to compute the net returns. It also conceptually states risk measurement and decision making under uncertainty.

4.1. Cost benefit analysis

Cost benefit analysis is a process to monetarily estimate all the consequence of a project or program faced by all the members of a society. It is a method to identify standings and all the costs and benefits, and valuing and analyzing an investment program. Benefits consist of the positive impacts and costs comprise of negative impacts. Projects evaluated by CBA, should include all the direct and indirect, market and non-market, individual and social, tangible and intangible costs and benefits. It valuate all the impacts and calculates the net benefits (benefits minus costs) of the project and these predicted estimates are used for making comparative analysis between the counterfactual situation or other projects of the same nature. The purpose is to make decision in such a way that scarce resources of society are used efficiently (Boardman *et al.,* 2006).

Broadly speaking, a cost benefit analysis takes all the private and social costs and benefits of the project. An investment project by a firm, for instance considers benefits in the form of revenues, employment opportunities and taxes, and costs as direct expenditures only. As a matter of fact, it contributes also to the environmental degradation and other types of non-market impacts to society, which are not evaluated. A CBA takes into account all the cost and benefits faced by the society as a whole. In other words, a CBA is a social cost-benefit analysis, which measures all the social benefits and social costs to all the members of society (Boardman *et al.,* 2006).

There are a few types of cost benefit analysis. The analysis which is conducted before the project implementation is called *ex ante* CBA. It is a standard technique and most commonly used in making cost benefit analysis. It directly and immediately influences the decision making process of the project or program. Another type is *ex post* CBA, which is carried out at the completion of the project. The purpose of this type of CBA is to provide information about a specific intervention of the invested project. A less familiar type of cost benefit analysis is to compare and contrast the *ex ante* and *ex post* estimates of CBA. This relative cost benefit analysis is useful in evaluating the effectiveness of the decision about a program. Occasionally, there is a need to conduct cost benefit analysis when some parts of the project are completed. This type of CBA is called *in medias res* cost benefit analysis (Boardman *et al.,* 2006).

A project analysed by CBA, usually undergoes the following steps as mentioned by Boardman *et al.* (2006):

1) Identify some alternative projects
2) Specify the standings of the projects (who will be affected)
3) Catalogue the impacts as pros and cons
4) Predict the unseen impacts of the project
5) Monetize the impacts

6) Obtain net present value of the impacts
7) Calculate net returns of the project
8) Perform sensitivity analysis
9) Make recommendations

Cost benefit analysis is applied when the net benefits of all the alternative projects are monetized, and the comparison is made among a range of projects and the status quo. Based on the positive and negative net returns, a decision is made to implement Pareto efficient projects (projects with positive net returns where all the loser agents are compensated). Cost-benefit analysis is questionable when goals other than efficiency are important. However, in such situations, CBA can be used to assess the relative efficiency of the projects (Boardman *et al.,* 2006).

The CBA of bio-ethanol and biodiesel, explored in this study, is a type of *ex-ante* CBA, an analysis that is being conducted before biofuel project implementation to assess the allocative efficiency of society's rare resources such as agricultural feedstock and other inputs. In addition, it provides guidance in selecting efficient project(s) among the alternative projects based on net profits generated by each project. The project with high net returns is considered efficient. However, in some cases, efficiency criteria are open to discussion and questionable (Boardman *et.al,* 2006). For example, goals other than efficiency are more significant when the aim is to meet the rising demand of energy. Moreover, it is hardly possible to value each cost and benefit in monetary terms such as all environmental impacts and real social cost and benefits society will have to bear. Especially guessing the costs and benefits, which are expected to arise after project start, can provide an illusive and misleading picture.

4.2. The deterministic model

The private net benefits of producing biofuels were assessed by calculating costs and benefits of each fuel, which is given by the following mathematical equation:

$$\pi_i\,(Q_i) = P_i Q_i - C_i(Q_i) \text{ ------------------ } (1) \quad i = 1\ldots4$$

Where

i	*corresponds to all the four feedstock-based production technologies, e.g., sugarcane, switchgrass, jatropha and corn*
$\Pi_i(Q_i)$	*economic net returns of each biofuel produced from i feedstocks*
P_i	*the price of biofuels as final product in the market*
C_i	*unit cost of each feedstock based biofuel*

The cost function for each of *i* biofuel; $C_i\ (Q_i)$ is given by:

$$\mathrm{C_i(Qi)} = \mathrm{wL_i + sS_i + nN_i + eU_i - mM_i} \text{ --------- } (2)$$

Where

w	*unit wages*
L_i	*quantity of labour force*
s	*unit price of feedstock*
S_i	*amount of feedstock used to extract per unit biofuel*

n per unit cost of chemicals
N_i related chemicals such as sulphuric acid, methanol etc.
e the price of electricity, biogas and coal
U_i amount of utilities e.g., electricity, biogas and and/or coal
m the market price of by-products
M_i by-products produced during conversion process

The costs for all the biofuels were estimated by the pattern given in equation 2. Thus, expression (1) can be written as:

$$\pi_i\,(Q_i) = P_iQ_i - (wL_i + sS_i + nN_i + eU_i - mM_i\,) \text{------------ (3)}$$

The first term of the expression (3) is generally called "benefits", which in this study includes benefits from sales of energy. The terms in parenthesis make the cost component of the net profits. It consists of the costs made on all the inputs and raw material such as feedstock, utilities, chemicals etc.

Putting in words, expression (3) presents the difference of benefits and costs in monetary values. In other words, it shows net returns, which corresponds to finding difference by adding all positives quantities (benefits) and deducing all the estimated negative quantities (costs). By applying equation (3), economic net profits of biofuels based on corn, jatropha, sugarcane and switchgrass were estimated.

To produce a positive quantity of biofuels, benefits must be greater than or equal to costs of conversion. In other words, net returns must be positive or equal to zero. Mathematically, it can be expressed as below:

$$\mathrm{P_iQ_i} - \mathrm{C_i(Q_i\,)} \geq 0 \text{ -------------- (3)}$$

Or

$$\pi_i(Q_i) \geq 0 \text{ ----------------- (4)}$$

The decision rules under uncertainty are also further discussed latter in this section.

Projects such as biofuels need resources that can be used to produce other goods and services or are already being consumed in another setting. Alternative bio-energy generation requires agricultural feedstock, land, labour, capital and other equipment. All these resources have their other different valuable uses. Especially in the context of a developing country where demand cannot be instantly met, resources sometimes need to be switched from one alternative to the other. These essentially entail estimating the opportunity costs of the inputs, which are assumed to be reflected in their market prices.

According to Boardman *et al.* (2011):

> *"Theoretically, opportunity costs equals the value of goods and services that would have been produced had the resources used in carrying them out been used instead in the best alternative way."*

When the biofuel producing agents start production of biofuel, they demand more of the inputs (especially feedstock), which, in this case, can increase the supply or shift the use of inputs towards energy purposes from other sectors. Thus, energy producers are facing a horizontal supply curve and will purchase additional quantity on the price they would have cost (loss of profits) in the absence of biofuel production projects. In other words, prices of

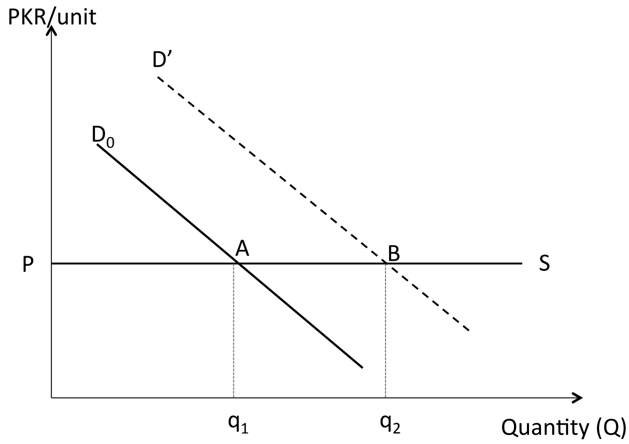


Fig. 3: Opportunity cost with perfectly elastic supply curve in competitive market

inputs are not affected. As shown in **Fig. 3**, assuming linear demand curve, due to the additional purchase of inputs, demand curve will shift upward from D_0 to D'. The horizontal supply curve, S, represents unchanged marginal cost and hence, no price change, P. The opportunity costs of one additional unit purchased are P and the opportunity cost faced by society is represented by rectangle ABq_1q_2. Consequently, the amount that the biofuel producers must pay for an additional unit is the opportunity cost of resources to produce it.

4.3. Risk Analysis

An *ex-ante* cost benefit analysis of biofuels requires predicting the future. Outcomes in the future may connect with risk, which are considered as variability in net returns of each feedstock based biofuel. Manufacturing cost of biofuels can vary from case to case depending on feedstock type and cost, productivity, cost of conversion, existing level of technology and production methodology, thus, resulting in different levels of net benefits.

The main objective of biofuel producers is to maximize the net returns while tackling the risk. In doing so, they can have different attitudes towards risk, for instance, they can be risk loving, risk neutral or risk averse. The one who is indifferent to risk, normally maximizes the net returns without considering the variability in net returns or risk; he or she is indifferent between high or low returns. On the other hand, a risk adverse producer takes cost variability or profit risk into account when deciding on the level of production. If two of the projects are equally profitable in terms of cost and benefits, it is the level of risk which helps in making decisions about investment e.g., decision is made to implement the project with low production risk.

Among many of the ways to measure risk, one method is to compute variance (and/or standard deviation) of the distribution of net returns (Business Finance Online). As net return is dependent on the sum/difference of some dependent variables (as given in equation 3), we can write variance as below:

$$\sigma^2 = Var(\pi_i) = Var(P_i) + Var(L_i) + Var(S_i) + Var(N_i) + Var(U_i) - Var(M_i) + 2Cov(P_i, L_i) + 2Cov(L_i, S_i) + 2Cov(S_i, N_i) + 2Cov(N_i, U_i) - 2Cov(U_i, M_i) - 2Cov(M_i, P_i) \text{------- } (5)$$

Where σ^2 is the symbol for variance; *Var* stand for variance and *Cov* is for covariance.

It is important and interesting to compute covariance and study the relationship between variables contributing to the cost. Zero correlation between random variables is assumed. Although this assumption is not reasonable, yet it is very challenging empirically. Thus, by assuming independence among the dependant variables, expression (4) takes the form of following equation:

$$\sigma^2 = Var(\pi_i) = Var(P_i) + Var(L_i) + Var(S_i) + Var(N_i) + Var(U_i) - Var(M_i) \text{--- } (6)$$

Portfolio analyses is applied where an expected profit-risk frontier is developed for each biofuel which shows the minimum risk for a given expected profits, or maximum profits for a given risk, which is written as

Objective function: $\max E[\pi(Q_i)]$ ---- (7)
Subject to $\sigma^2(Q_i) \leq \bar{\sigma}^2$

The expected profit-risk frontier is obtained by solving (6) for different levels of the maximum risk, i.e. $\bar{\sigma}^2$. The solutions give rise to a frontier which is illustrated in Figure 4.

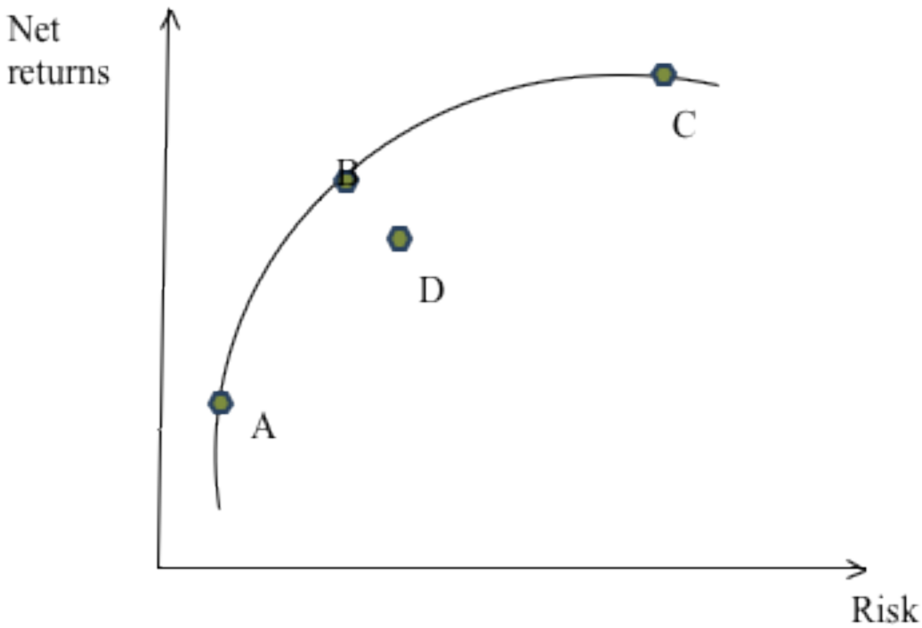


Fig. 4: Expected profit-risk frontier

In the setting of this thesis, investment decision is affected by the mean and variance of net returns. To illustrate the behaviour of risk and net return, a profit-risk Frontier is drawn in **Fig. 4**. It reflects the trade-off between the level of net returns and risk associated with this level. At point A, the level of risk is very low as well as it represents small profits. If a producer wants to increase production to achieve more profit, so to say, at point B, he has to accept higher risk. As he goes on in his effort to earn high profits, it becomes more and more risky. On the other side, it is easier to reduce risk while being at point C than at point B. Due to the increasing slope of the frontier, the producer has to face more reduction in profit at point B than at C if he tries to reduce risk. Furthermore, given points C and D, point C performs better in terms of risk and net returns; lower level of risk and higher profits, yet it is not feasible to adopt as it doesn't exist on the frontier. Thus, all the points below the curve are inefficient. The actual portfolio choice is determined by the risk attitudes, the higher risk aversion the lower risk and net returns, and vice versa. However, this thesis will not assess risk attitudes but only derive the frontier illustrated in Figure 4.

As the task of this study is to calculate net returns of all feedstock based biofuels, variance of only net returns can be measured instead of computing variance of all the dependant variables. (Net returns are given in section 4.1.) Maximum and minimum net profits of each of the biofuels were specified and then statistical values (mean and variance) were applied. In doing so, Monte Carlo Simulations[11] were used to obtain relatively accurate quantities of mean and variance.

4.4. Other decision rules under uncertainty

Due to expected uncertainty in net returns, it was thought to be useful to look for some other rules for making decisions related to production, in addition to the port folio analyses. In this regard, few types of rules were discussed and analysed as given by Perman *et al.* (2006):

1. Maximin rule
2. Maximax rule
3. Minimax regret rule
4. Best worst choices

To look at the rules theoretically, consider **Table 2** and **Table 3** which define the net returns under different standards for all the four type of biofuels.

Maximin rule: this rule is known as the pessimistic approach. Under this criterion, the producer considers only minimum payoffs of the alternative projects and selects the one with the least bad outcome. This rule maximizes the minimum net returns. It is useful when minimum outcome is more likely to occur or its occurrence may result in an extreme loss (Reynolds and Schaeffer). However, the maximin decision rule depicts that the decisions are made by ignoring the other entire outcome, hence only keeping the worst outcome in mind (Perman *et. al.,* 2006).

In **Table 2**, four strategies 1, 2, 3 and 4 with three types of payoffs (A, B and C) are given. Payoffs ($\Pi_i^{min/max/average}(Q_i)$) are net returns with the range of minimum, maximum and average standards for all the three types of payoffs. The investor of biofuels projects chooses production of a project (1, 2, 3 or 4), which gives the least bad net returns.

[11] Monte Carlo simulation is a method usually applied for assessing risk. It is used to check the factor of uncertainty and variation of the outcomes. It is commonly known as a computer based technique which requires limits of possible outcomes for random simulation of outcomes.

Table 2: Net returns matrix

	A	B	C
1	$\Pi_1^{min}(Q_1)$	$\Pi_1^{max}(Q_1)$	$\Pi_1^{average}(Q_1)$
2	$\Pi_2^{min}(Q_2)$	$\Pi_2^{max}(Q_2)$	$\Pi_2^{average}(Q_2)$
3	$\Pi_3^{min}(Q_3)$	$\Pi_3^{max}(Q_3)$	$\Pi_3^{average}(Q_3)$
4	$\Pi_4^{min}(Q_4)$	$\Pi_4^{max}(Q_4)$	$\Pi_4^{average}(Q_4)$

Maximax rule: this optimistic approach attracts the decision maker who wants to earn the highest profit. Under this criterion, the producer considers only maximum payoffs of the alternative projects and selects the one with best outcome (Reynolds and Schaeffer). Similar to maximin, this rule also does not take into account all the net returns but looks at only the best outcome (Perman *et. al.,* 2006).

This rule selects the best of the best action (*1, 2, 3* or *4*) from the given net returns on the pattern of **table 2.**

Minimax regret rule: To avoid costly mistakes, a cautious decision maker makes use of the regret matrix. A usual payoff matrix (**Table 2**) is transformed to a regret matrix (**Table 3**) by specifying the larger payoff for each strategy and then stating the other payoff as a deviation from the larger (Perman *et. al.,* 2006). As this is a minimax regret rule, it suggests that the decision maker examines maximum regret of each strategy and chooses the value with minimum regret. This criterion is useful if the producer is curious about the comparative performance of alternatives (Reynolds and Schaeffer).

For the purpose of building the regret matrix, we assume that $\Pi_1^{max}(Q_1)$, $\Pi_2^{max}(Q_2)$, $\Pi_3^{min}(Q_3)$ and $\Pi_4^{min}(Q_4)$ are larger payoffs in each of the four rows (alternative projects). The regret matrix (the difference of the larger and smaller) (**Table 3**) explains the actions in regret and the action (1, 2, 3 or 4) with minimum regret (from the specified maximum regret) will be selected.

Table 3: Regret matrix

	A	B	C
1	$\Pi_1^{max}(Q_1)-\Pi_1^{min}(Q_1)$	0	$\Pi_1^{max}(Q_1)-\Pi_1^{average}(Q_1)$
2	$\Pi_2^{max}(Q_2)-\Pi_2^{min}(Q_2)$	0	$\Pi_2^{max}(Q_2)-\Pi_2^{average}(Q_2)$
3	0	$\Pi_3^{min}(Q_3)-\Pi_3^{max}(Q_3)$	$\Pi_3^{min}(Q_3)-\Pi_3^{average}(Q_3)$
4	0	$\Pi_4^{min}(Q_4)-\Pi_4^{max}(Q_4)$	$\Pi_4^{min}(Q_4)-\Pi_4^{average}(Q_4)$

Best worst choices: As mentioned earlier, in this study, minimum and maximum costs and benefits are specified in a range of different standards of biofuel production and net returns are clearly the difference between maximum costs and maximum benefits and so on. However, in the presence of uncertainty, net returns from minimum costs and maximum benefits can happen instead of net returns resulting from minimum costs and minimum benefits. For example, bad weather can destroy crop, which results in lower quantity of feedstock. In this condition, producers of biofuels have to face increases in the price of feedstock and rise in production costs. On the other hand, his/her profit may be affected by lower biofuel prices in the international market. For this reason, it will be helpful to check the situations when everything does not happen as scheduled. Thus, we can write this rule as:

Best choices: $Max\ B_i - Min\ C_i = \pi_i^{best}$
Worst choices: $Min\ B_i - Max\ C_i = \pi_i^{worst}$

Where

B Benefits
C Costs
Π Net returns
i= 1…4 (all the four feedstocks used for biofuel, sugarcane, corn, molasses and jatropha)

Combining all the choices can form a matrix (discussed in the Results section). The decision, when matrix of best and worst choices is given, depends on the net return in each case. The case with high returns will be selected to process.

Due to volatility in net returns, different selection criteria are given and discussed above. All these suggest different actions to be taken under uncertainty. However, the selection of method mainly depends on the nature of the producer and on his basic preferences.

The next section describes data retrievals, which are empirically processed in section 6 according to the theoretical concepts presented in this section.

5. Description of data

As mentioned under section 1, sugarcane, corn, switchgrass and jatropha were selected from a variety of biofuel feedstocks. This section provides details of these selected feedstocks and presents the data. In addition, a brief description of data type, sources of data, assumptions related to input data are provided.

Data used in this study for feedstock-based biofuels was collected by standardized method (data collected by others) and secondary data was utilized to evaluate various scenarios of biofuel production in the region. Secondary data sources include research articles, energy yearbooks and databases related to prices. Owing to the unavailability of local input data for fuel conversion, estimates from neighbouring countries and efficient manufacturer economies were transferred. The author made further calculations and adjustments of data in accordance with minimum and maximum standards. Inputs related to data for biofuels were taken from India for jatropha, from Thailand for cane molasses and for switch grass and corn; it was transferred from estimates made in United States. In this regard, only the quantity of inputs was taken and prices were estimated as of the local market. However, for some inputs the same costs/price, as was given in the original source, was used. For the biofuel prices, international prices were employed.

Due to lack of data and specific hurdles related to the collection of input figures for the production of biofuels, the cost component of net profits consists of only variable costs. Costs of biofuel investment vary across places depending on technological advancements and local setup. Furthermore, it was assumed that (1) biofuel is produced from large and small scale plants and this distinction was adopted to get minimum and maximum costs, (2) costs, benefits and net returns of a specific quantity (100 litres) were estimated, (3) prices of by–products were deduced from the costs of production, and (4) all the taxes and subsidies are ignored for the purpose of comparison among various feedstock based biofuels.

As estimates were transferred from different countries, which were given in different years. In such a case, the currency units of prices were converted to the currency of Pakistan (Pakistani Rupee, PKR), on the bases of PPP (purchasing power parity) exchange rate. An exchange rate (PPP based) of 1USD = 35.77PKR as of 2011 was applied (IMF, 2011). The data was also adjusted to inflation rates of 2011 using GDP (gross domestic product) deflator[12]. GDP price deflator is preferred to CPI (consumer price index) because it is not based on a fixed bundle of goods. Moreover, it automatically reflects the change resulting from an introduction of new goods and services, and variations in consumption habits (Investopedia, 2012). Implying following formula inflation adjustments were made:

$$\text{Value in 2011} = \text{ value in period t} * \left(\frac{\text{GDP deflator in 2011}}{\text{GDP deflator in period t}}\right)$$

The data for GDP deflator was used from IMF, which was approximately similar to the World Bank.

[12] An economic metric that accounts for inflation by converting output measured at current prices into constant-dollar GDP. The GDP deflator (also known as the "GDP implicit price deflator") shows how much a change in the base year's GDP relies upon changes in the price level. Explained by Investopedia; http://www.investopedia.com/terms/g/gdppricedeflator.asp#ixzz3c42H89S5

5.1. Sugarcane

Picture 1: Process of can ethanol from sugarcane production to ethanol

Sugarcane is the least priced source of biodiesel production, which can produce large fuel quantities at relatively low cost (e.g., $387 /ton in Brazil). It is mainly produced on wide area for food purposes across the world (**Fig. 5** shows the production by country in 2010). Simpler procedure and lowest cost of ethanol conversion (Shapouri *et al.,* 2006) made it favourable to cultivate for renewable fuel. Furthermore, cane ethanol is environmentally efficient as it reduces CO_2 emission by up to 90% as compared to petro fuel (Hira, 2011) and can cut down green house gas (GHG) emissions by more than 80% (Almeida *et al*., 2007).

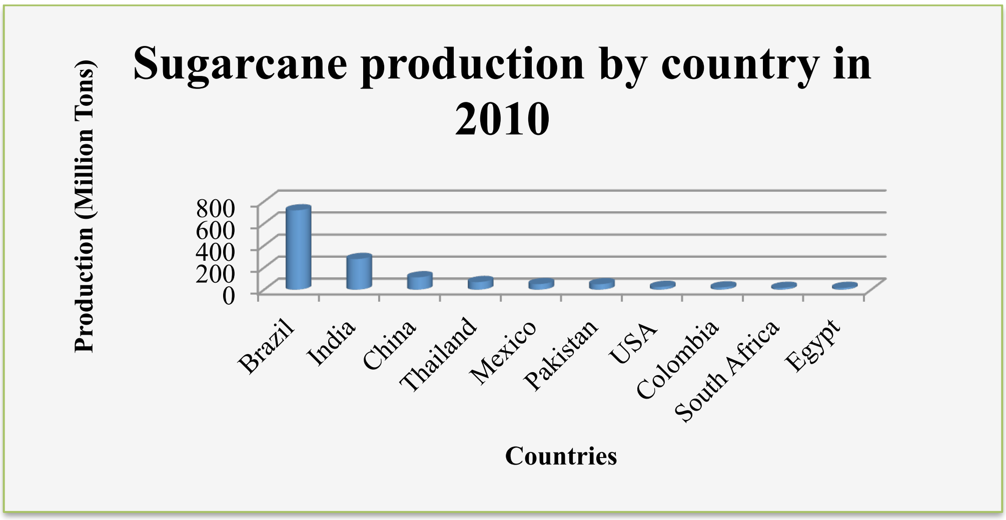


Fig. 5: Sugarcane production by country in 2010[13]

Biofuel extraction from by-products and non-edible feedstock make it exempted from food vs. fuel concern. For instance, from sugarcane, two main by-products bagasse and molasses are produced, from which molasses can be easily converted to ethanol by fermentation without any pre-hydrolysis (Shapouri *et al.,* 2006) and bagasse provides energy for refinery

[13] Source: http://faostat.fao.org/DesktopDefault.aspx?PageID=339&lang=en&country=165

and distillation (Rashid and Altaf, 2008). This technique currently enjoys the advantages of sufficient supply (of sugarcane), feedstock (molasses) production infrastructure and existing conversion technology (Nguyen and Gheewala, 2008).

Ethanol production from molasses contains three main steps; sugarcane production, molasses production (as a by-product) and ethanol conversion through fermentation. Nguyen and Gheewala (2008) have presented molasses ethanol cycle, which is shown in **Fig. 6** with minor alteration according to production possibility circumstances. Sugarcane cultivation requires land, human labour, irrigation, fertilizers and pesticides, machinery, crop rotation etc. as inputs and sent for sugar milling where one main product (sugar, 10.4%) and two by-products (bagasse, 24.8% and molasses, 4-4.5%) are produced (Nguyen and Gheewala, 2008; Khanji *et al.,* 2009). Molasses is converted to ethanol (ethyl alcohol) by simple fermentation procedure.

Pakistan is among the biggest producers of sugarcane in the world (**Fig. 5**). Cane is a cash crop whose contribution to GDP is 0.8% (PES, 2010-11). It is cultivated on a large proportion of agricultural land and primarily used or sugar and gur (jiggery) production. Around 53500 thousand tons of sugar cane is produced yearly in the country (Khanji *et al.,* 2009). According to the national statistics of Pakistan Sugar Mills Association (PSMA), in 2010-11, cane cultivation area was estimated at an equivalent of 987.7 thousand hectares which yielded a crop of 55.42 million tons, a 12% increase over the production of last year.

Sugarcane is primarily used to manufacture sugar. In this process, by-products e.g., molasses and bagasse are produced in relatively high quantity. Bagasse is normally used indigenously by sugar mills for both heat and electricity production while molasses is exported in raw form or converted to industrial ethanol. Molasses production is on average 2 million tons from cane crushed every year and 21 ethanol production units have been installed near sugar mills with ethanol production capacity of 400 thousand tons. If all the molasses is utilized in ethanol production, on average 457.6 million litres of ethanol can be produced (**Fig. 2**).

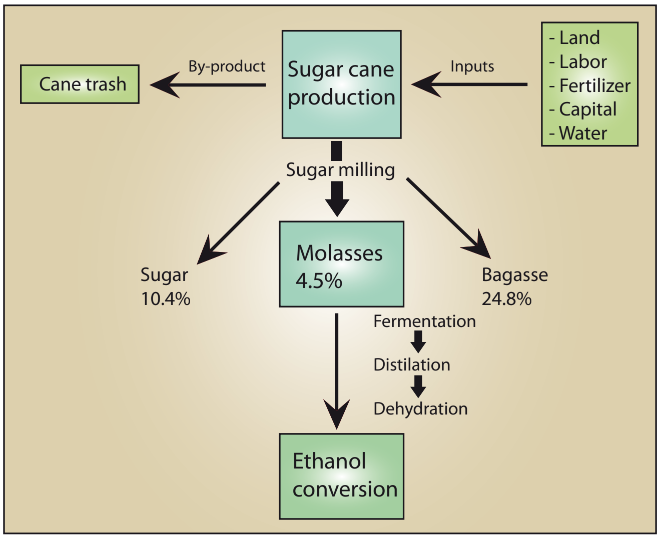


Fig. 6: Production chain of ethanol from cane molasses

In Pakistan, sugarcane-based ethanol is only produced from molasses. That's why, for the procedure of ethanol conversion, estimates are taken from Thailand. Normally, molasses is only 4-4.5 % of cane crushed and estimates by Ali *et al.* (2012) and Harijan *et al.* (2009) show that 240-270 litre ethanol can be obtained from a ton of molasses depending on the quality of molasses in Pakistani distillery units which are usually connected to sugar mills. This is the main distinction point between Min (minimum) and Max (maximum) estimates made in data collection where minimum quantity requirement to produce 100 litres ethanol is 370 kilogram and for maximum, 416 kg of molasses is needed.

Table 4: Ethanol Production from cane molasses; input requirement and costs per 100 L of ethanol

		Quantity per 100 L			**Cost PKR/100 L**		
	unit	Min	Max	Average	Min	Max	Average
Ethanol Conversion							
Molasses	kg	370[a]	416[a]	393	2164.50[b]	2433.60[b]	2299.1
Electricity	kWh	31.45	35.36	33.405	204.43[c]	229.84[c]	217.13
Rice husk	kg	44.17	49.66	46.915	63.20[d]	71.05[d]	67.124
Biogas	L	1538.3	1729.58	1633.959	0[e]	0	0
Biogas (By-product)	L	-1538.3	-1729.6	-1633.96	0[e]	0	0
Purification of ethanol[f]					31	35	33

[a] Ali *et al.,* (2012) and Harijan *et al.,* (2009).

[b] Prices obtain from Thailand and converted to PKR based on PPP-exchange rate and are inflation adjusted to 2011.

[c] adopted from: http://www.wapda.gov.pk/htmls/customer-index.html.

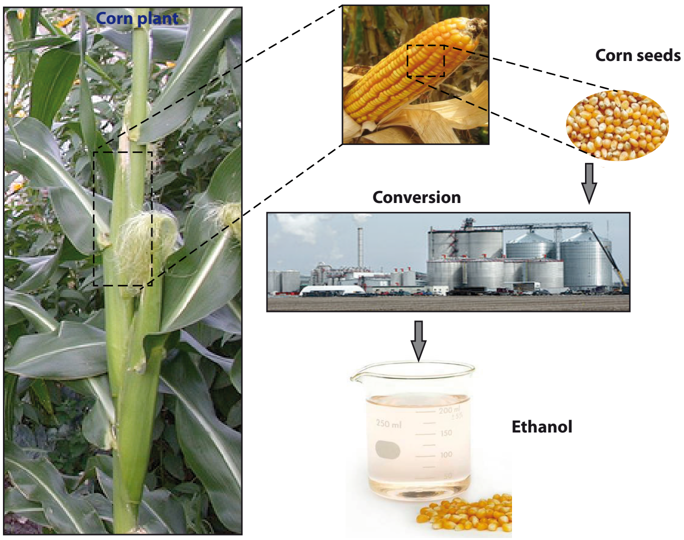
[d] Rice husk price is 40 USD/ton in Asia according to: http://www.rcogenasia.com/biomass-power-cogen-2/rice-husk-to-power/.

[e] Prices are zero due to by-product (biogas).

[f] Water needs to removed from ethanol to make it 99.5% pure to further blend with petrol. Estimates from Pimentel and Patzek (2007).

The other inputs, rice husk, electricity, biogas and diesel required in the fermentation process are used as given by Nguyen *et al.* (2008). The similar amount of biogas (as required in output) is generated during the conversion processes, which neutralizes the cost of biogas as an input. The required quantities and their costs are given in **Table 4**. The biggest contributor to cost is the feedstock cost, which is 2299.1 PKR/100 litres, followed by electricity. Ethanol produced at the end of the fermentation process needs to be purified to mix in gasoline and this also adds to the cost.

5.2. Corn



Picture 2: Corn ethanol processing

Corn (maize) is one of the most commonly grown perennial crops and is the third largest food item after wheat and rice in Pakistan. It is experiencing significant growth of about 9.6% for the last few years and production is on average 3.3 million tons per year (**Fig. 7**) (Farooq, 2011). It is mainly used as human and animal feed. Another consideration is converting corn to biofuel to meet the ever-rising demand for energy. However, currently there is no noteworthy ongoing practice of biofuel production from this feedstock in Pakistan. Hence, internationally, there are notable examples of large proportion of corn converted to fuel, which can provide guidance to promote this technology. For example, only in the United States, almost 40% (130 million tons) of corn is used for the production of ethanol, a source of bio-energy (Pimentel and Patzek, 2005). Therefore, the presence of suitable climate for feedstock cultivation, cost effectiveness of corn ethanol production and conversion has made it reasonable to select corn for assessment in this study.

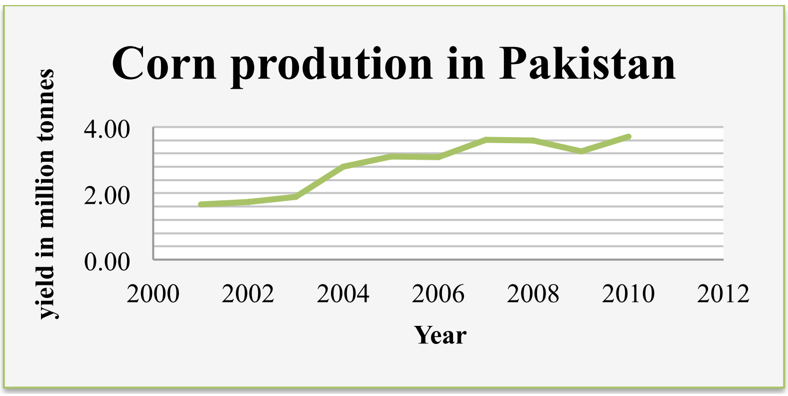


Fig. 7: Total production quantity of corn in Pakistan from 2001 to 2010[14]

[14] Source http://faostat3.fao.org/home/index.html

Crop yield per hectare varies across regions due to cultivation techniques, climate, properties of tillable land etc. At the same time, there are various methods and techniques to convert corn to ethanol. Commonly used cost effective techniques are fermentation/distillation and mass of ash. By the application of fermentation/distillation and use of large, modern plant, 2.69 kg of corn grain can produce one litre of ethanol (Pimentel and Patzek, 2005). On the other hand, FAPRI (2006) suggests that 2.26 kg ethanol is required for 1-liter ethanol production. I had used these two different criteria to estimate various costs related to bio-ethanol production by distillation process.

Table 5: Input use and cost in Corn ethanol production (/100 litres)

	Unit	Quantity (/100 litres)			Cost (PKR/100 litres)		
		Min	Max	Average	Min	Max	Average
Feedstock cost							
Corn grain	kg	225.6	269	247.3	2362.03[a]	2816.43[a]	2589.23[a]
Ethanol conversion							
Water	L	3384[b]	4000	3692	68.76	81.44	75.10
Electricity	kWh	32.8	39.2	36	213.20[c]	254.80[c]	234.00[c]
Water removal form ethanol mixture [d]	L	1300	1300	1300	153.66	153.66	153.66
Sewage effluent [e]	kg, BOD	2	2	2	23.05	23.05	23.05

[a] World commodity prices by World Bank in 2011 average, available at: Source: http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTDECPROSPECTS/0,,contentMDK:21574907~menuPK:7859231~pagePK:64165401~piPK:64165026~theSitePK:476883,00.html,

[b] Pimentel and Patzek, 2005; 15 l of water mixed with each kg of grain and 1890.4 litres of water cost 35.7 PKR,

[c] 6.5 PKR/kWh available at: http://www.wapda.gov.pk/htmls/customer-index.html,

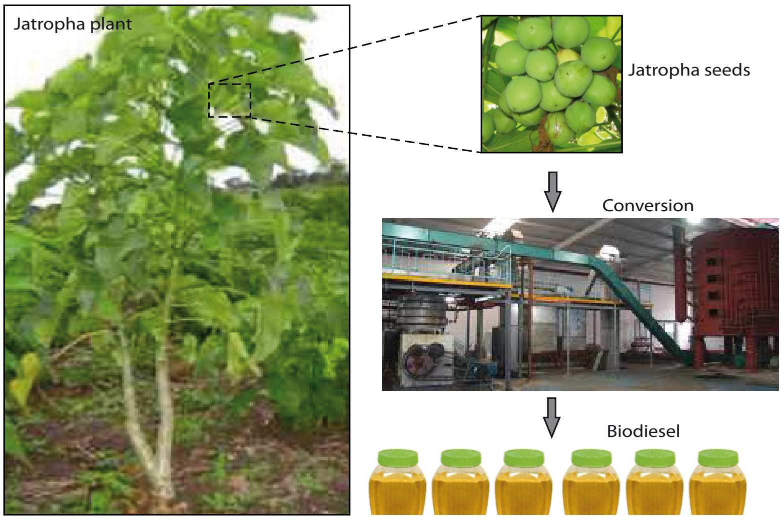
[d] Ethanol 95% to 99.5% pure for blending in gasoline. Estimates transferred from Pimentel and Patzek (2005).

[e] Pimentel and Patzek (2005).

Table 5 presents the input required to produce corn ethanol. As feedstock production and fuel conversion estimates were transferred from United States, inputs used for feedstock production were not considered here due to differences related to cultivation, climatic conditions, input applied per hectare, technological advancements etc. Only the corn quantity required for 100 litre ethanol was taken and then prices were adopted from current agricultural prices in Pakistan. For ethanol transformation, the process as well as input quantity were used as of United States standards while prices were used from Pakistan if available, otherwise these were PPP and inflation adjusted to 2011 from original studies.

It is obvious from **table 5** that the main contributor to the cost of production is the feedstock price followed by electricity used in the process. Ethanol produced at the end is not the standardized ethanol (mixture of water and ethanol) that can be blended in gasoline. It needs to be processed by removing water to get 99.5% ethanol (Pimentel and Patzek, 2005) and requires relatively large expenditure.

5.3. Jatropha



Picture 3: Jatropha biodiesel processing

Jatropha curcas is an oil-yielding plant being considered a best potential feedstock for the production of biodiesel. It is a non-edible crop, widely grown in wild areas of the tropics and subtropics (Wang *et al.,* 2011). It possesses the qualities of high resilience to environmental variability (drought resistance, favourable survival rate etc.) and high oil content (30 to 40%) in seeds, and yields more or less equivalent productivity on marginal land (Kritana and Gheewala, 2008; Wang *et al.*, 2011). Carriquiry *et al*., (2011) has analyzed that oil extraction from jatropha is between 1800-2800l/ha/yr, which is the highest compared to other oil yielding plants, e.g., canola, rapeseed and soybean. Moreover, according to many life cycle assessment studies (Kritana and Gheewala, 2006 and Wang *et al*., 2011), it is environmental friendly in terms of CO_2 and green house gas emissions. However, an unproven and preliminary consideration is more emission due to additional use of fertilizers in feedstock production.

Seed yield varies across countries depending on existing technologies and production conditions (land, water, fertilizers etc), which ranges from 0.4 to12 t/ha/yr (**Table 6**) (Carriquiry *et al.,* 2011 and Wang *et al.,* 2011). This difference in yield varies from semi-arid wasteland to good quality soil with annual rainfall of 900-1200 mm.

Table 6: Yield/HA and Oil yield from jatropha seeds[15]

	Min	**Max**	**Average**
Yield (t/ha/yr)[a]	1	5	3
Oil yield (litres/ton)[b]	304.8	1524	914.4

[a] Production at wasteland
[b] Oil contents of seeds are assumed to be 33%, i.e. 3.28 kg seeds produce 1 kg (litre) Jatropha oil.

Oil produced from Jatropha can meet international standards. It can be burnt directly or transformed easily to liquid biodiesel. The transformed biodiesel is blended with petro-diesel (Wang *et al.*, 2011). Life cycle of Jatropha biodiesel production (from feedstock cultivation to

[15] Source: Kukrika, 2008.

oil consumption) is briefly described in **Fig. 8**. It discusses the use of inputs (labour, land, capital, water technology etc.) at every stage of productions, the main process and by-products (wood, cake-seed and glycerine) produced as a result of feedstock cultivation and biodiesel conversion.

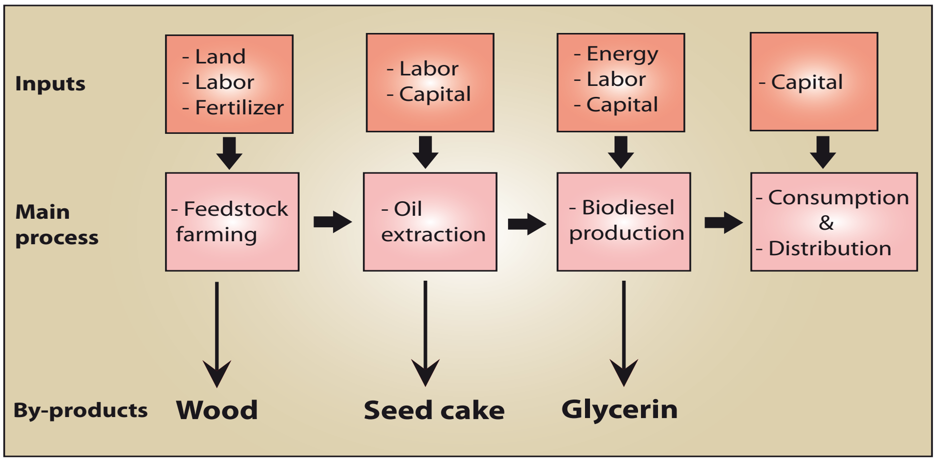


Fig. 8: Production chain of Jatropha oil

As mentioned earlier, in Pakistan, there are wide areas of wasteland (**Table 1**) due to the shortage of water, salinity, high temperature etc. Besides, jatropha is biologically feasible and gives a high yield in Pakistan as depicted by the experimental cultivation done by the Pakistan State oil (PSO) and the Pakistan Agricultural Research Council. Moreover, governmental agencies are eager to enhance biodiesel blends for energy purposes and giving a helping hand to provide favourable circumstances for feedstock production, conversion, machinery import etc.

The estimates applied in this study are of marginal land where it is assumed that yield is 1-5 tons/ha/yr starting from the 3rd year of cultivation and 3.28 kg seeds are required for one litre of Jatropha biodiesel (**Table 6**). This difference in yield varies from semi-arid wasteland to good quality soil with annual rainfall of 900-1200 mm. Due to resemblance in climate, soil quality, average rainfall, the estimates are transferred from closest neighbour; India, as presented by Kukrika (2008).

Table 7: Jatropha based biodiesel costs PKR/100 litres[c] [16]

	Cost in PKR per 100 litres		
	Min	**Max**	**Average**
Feedstock cost	953	3717.4	2334.6
Biodiesel production			
Methanol	349.5	349.5	349.5
KOH	0.0	0.0	0.0
Electricity, water and other	95.3	95.3	95.3
Yield loss (10%)	31.8	31.8	31.8
By-product (seed-cake)	-162.0	-162.0	-162.0
By-product (glycerol)	-276.4	-413.0	-344.7

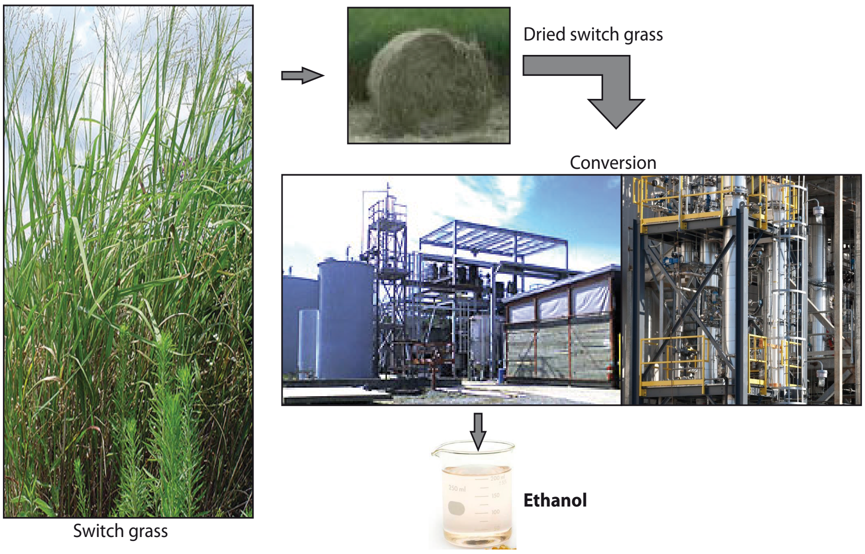
[c] Original costs are given in 2008 US dollar which is converted to PKR using 2008 PPP exchange rate and inflation adjusted to 2011 using GDP deflator.

[16] Source: Kukrika (2008), Carriquiry *et al.*, 2011

All the costs for biodiesel extraction from the given feedstock are discussed in details follows:

- *Feedstock cost:* feedstock required for 100 litres of biodiesel is bought from the market, which is the major component of total costs.
- *Biodiesel production:* Although, biodiesel conversion from Jatropha oil is a simplified procedure yet it requires certain inputs to yield good quality transport oil. Electricity, water, methanol, potassium hydro-oxide etc. are utilized during conversion process. A loss of 10% yield of oil is also included in these types of costs.
- *By products:* As shown in **Fig. 8** and **Table 7**, many types of by-products are produced at various production and conversion stages (wood from pruning, cake-seed from oil extraction and glycerine from biodiesel conversion). The value of these by-products is deduced from the total costs. Cake-seed is also used as a natural fertilizer. Fertilizer cost is already included in the plantation and value of cake-seed is subtracted.

5.4. Switch grass



Picture 4: Ethanol production from switchgrass

A cellulosic herbaceous feedstock for bio-energy, switch grass is a tall grass of warm season, which is indigenous to both Central and North America. Switch grass is considered an ideal candidate for ethanol production due to its tall size of about 10 feet, high cellulose contents, and drought and flooding tolerance, relatively low herbicide and fertilizer input requirements, ease of management, hardiness in poor soil and climatic conditions, and widespread adaptability in temperate climates (Samson *et al.,* 2004).

The productivity of switch grass is also very high, which is estimated to be around 5.5-11 dried t/ha/yr from normal quality land (McLaughlin, and Kzos, 2005; Schmer *et al.,* 2008; Pimentel and Patzek, 2005 and Vadas *et al.,* 2008) and 18-27 t/ha/yr from good quality arid land (Carriquiry *et al.,* 2011). Ethanol yield per hectare is also profitably high which is according to estimates by the study of Pimentel and Patzek (2005) 400 litres from 1 ton of dried switch grass as 2.5 kg biomass is required for one litre of ethanol. On the other hand, Schmer *et al.,* (2008) has estimated the conversion rate of 0.38 litre ethanol per kg switch grass. These two transformation standards are used as the base for uncertainty in ethanol production based on switch grass.

Despite an efficient source of bio-energy, a recent study conducted by Le *et al.,* (2011) showed a downside of the switch grass. They stated that switchgrass is very effective in sucking water out of the ground. This negatively affects the production of other crops for human consumption as well as adversely affects local ecosystems. However, these actions of switch grass can effectively be exploited by cultivation of switch grass in the areas where water can be a hazard harbouring mosquitoes, a major cause of malaria. In Pakistan, every year thousands acres of land is wasted due to salinity and high underground water level. Growing switch grass in the area with high underground water level will not only work to reduced excess water level but also to acquire feedstock for fuel generation.

Table 8: Ethanol production from switchgrass, input requirement and costs per 100 L of ethanol

	Unit	**Quantity for 100 litre ethanol**			**Price in PKR for 100 litre ethanol**		
		Min	**Max**	**Aver.**	**Min**	**Max**	**Aver.**
Feedstock production cost							
Switch grass	Kg	250	263	256.5	960.3954 [a]	1010.34 [a]	985.37 [a]
Ethanol production from feedstock							
Water [b]	kg	3750	3945	3847.5	70.82	74.50	72.66
Grinding grass [c]	kg	250	263	256.5	30.73	32.26	31.50
Sulphuric acid [d]	kg	1.18	1.242	1.21	317.30	333.97	325.64
Steam production [e]	kg	810	852.12	831.06	138.30	145.20	141.75
Electricity [b]	k Wh	66	70	68	429	455	442
Ethanol conversion to 99.5% [e]					153.66	161.34	157.50
Sewage effluent [b]	kg	2	2	2	23.05	23.05	23.05
Co products (Yeast etc.) [f]					-153.66	-161.34	-157.50

[a] Pimentel and Patzek, 2005.
[b] Costs and prices are as given in table 4.
[c] Pimentel and Patzek, 2005.
[d] Sulphuric acid price is 268.9 PKR/kg. It is diluted with water and can be recycled 10 times.
[e] Pimentel and Patzek, 2005.
[f] Carriquiry et al., 2011.

Regardless of high yield per hectare, this study only took into account the conversion properties of switchgrass to ethanol in this study. The earlier mentioned transformation standards by Pimentel and Patzek (2005) and Schmer *et al.* (2008) are used as the base for uncertainty in ethanol production based on switch grass. Other inputs are the requirements of a commonly known conversion technique, fermentation.

As shown in **Table 8**, the major part of costs goes to feedstock cultivation followed by electricity used in conversion process. Sulphuric acid consumption is also a big contribution to costs, although it is used as diluted form and is recyclable for 10 times. Co-product, brewer's yeast which neutralizes the cost of purification (ethanol conversion to 99.5% pure ethanol), is only 0.025 kg per 100 litres of ethanol but still its value fulfils the cost of cleansing ethanol. Steam is another major energy input while converting switch grass to ethanol (Pimentel and Patzek, 2005).

5.5. Biofuel prices

Estimates of biofuel (ethanol and biodiesel) prices were acquired from OECD-FAO Agricultural Outlook 2011-2020[17]. These prices are international prices adapted from the world's leading markets (ethanol price from Brazil and bio-diesel price from Germany), which provide best estimates of the overall costs associated with fuel production. As for prevailing biofuel prices in Pakistan, E-10 gasoline prices are available from 1st of January 2010 (PSO, Pakistan). However, authentic prices for pure ethanol or biodiesel are difficult to attain. Therefore, it is plausible to make use of international prices as an approximation of internal prices (**Table 9**).

Table 9: Biofuel prices in PKR per 100 litres [a, 18]

Year	Ethanol	Biodiesel
2006	1790.89	3600.64
2007	1568.26	3998.52
2008	1736.62	5631.12
2009	1623.90	4142.90
2010	2127.17	4343.13
2011	2303.52	5099.23

[a] the original figures are in USD per 100 litres and were converted to PKR per 100 litres using PPP-based exchange rate of corresponding year. Inflation is adjusted to 2011 using GDP deflator.

In order to measure the risk of fluctuations in biofuel prices, variations in the last five years adjusted prices were taken into account where range from lowest to highest price will be used (lowest price as min and highest price as max, in this analysis).

[17]Biofuel-OECD-FAO Agricultural outlook 2011-2020. Available at: http://stats.oecd.org/viewhtml.aspx?QueryId=30104&vh=0000&vf=0&l&il=blank&lang=en

[18] Source: http://stats.oecd.org/viewhtml.aspx?QueryId=30104&vh=0000&vf=0&l&il=blank&lang=en

6. Results

In this section, results obtained from data analysis are presented in accordance to theoretical concepts discussed in section 4. Since the aim of the study was to analyse the net returns of biofuel production, this section accounts for net returns of all four types of biofuels. It also describes and compares costs and benefits, and presents the results in suitable graphs and charts. Finally, the results of risk analyses and various decisions making strategies, under uncertainty, are discussed.

6.1. Net return of biofuels

Following the pattern of expression equation 3 (under section 4.2), cost, benefits and net returns of jatropha, corn, switchgrass and sugarcane were simulated. Net benefits in the range of minimum (Min), maximum (Max), and average standards were measured. Regarding costs, maximum costs are the cost that producers have to bear for producing biofuel from a small size modern plant with relatively more requirement of feedstock quantity. For minimum costs, estimates were used for large sized modern plant and improved technology, which needs less quantity of feedstock and other inputs. As mentioned earlier (in section 5.5), benefits are the lowest as well as highest prices of biofuels in the international market for the previous five years. Average standard for all costs benefits and net returns are the results generated by Monte Carlo simulations (500 repetitions).

As summarized in **Table 9** and **Table 10**, benefits of biodiesel (produced from jatropha) are more than double that of bio-ethanol (extracted from corn, switchgrass and sugarcane). Net profit of jatropha biodiesel is significantly high and is the only positive returns in the series of biofuels analysed in this study. The big difference in both the costs (of jatropha) was mainly due to the different conversion requirements of feedstock for biodiesel production. On average, jatropha can yield around 23 PKR profit for the production of a litre of diesel. For corn and sugarcane, profit is negative and it does not differ very much between minimum and maximum range. Although, the level of negative net returns is less severe for sugarcane, net returns under maximum standard are positive for switchgrass and are negative for minimum and mean standards. Taken together, corn exhibits the highest loss in biofuel conversion by generating the lowest net profit while jatropha stays at top of the list in profitability.

Table 10: Benefits, cost and net returns of biofuel from jatropha, corn, switchgrass and sugarcane in PKR/100 litre

		Min	Max	Average
Jatropha	Benefits	3600.6	5631.1	4603.4
	Costs	991.3	3618.8	2315.6
	Net returns	**2609.3**	**2012.3**	**2287.7**
Corn	Benefits	1568.3	2303.5	1924.7
	Costs	2820.7	3329.4	3072.4
	Net returns	**-1252.5**	**-1025.7**	**-1147.7**
Switchgrass	Benefits	1568.3	2303.5	1949.9
	Costs	1969.6	2074.3	2021.2
	Net returns	**-401.3**	**229.2**	**-71.3**
Sugarcane	Benefits	1568.3	2303.5	1927.3
	Costs	2463.1	2769.5	2619.2
	Net returns	**-894.9**	**-466.0**	**-691.9**

Since costs exceed benefits, which result in a loss of production from corn, switchgrass and sugarcane, ethanol is infeasible to produce. As mentioned earlier in the section related to the description of data, the largest contributor to the costs was the feedstock. Therefore, breakeven price for all the feedstock was calculated, assuming all other components constant. For this purpose, a sensitivity analysis was performed. It was achieved by lowering the feedstock prices until net returns became positive. The results were summarized in **Fig. 9**, which indicate that a 45% decrease in feedstock prices can make all the biofuel production technologies feasible to proceed. Individually, if the price of switchgrass is decreased by 8%, cane molasses by 30% and corn by 44%, all the biofuels become economically feasible to produce. Hence, the breakeven price for corn, cane molasses and switchgrass was found to be 5.9, 4.0 and 3.5 PKR/Kg, respectively.

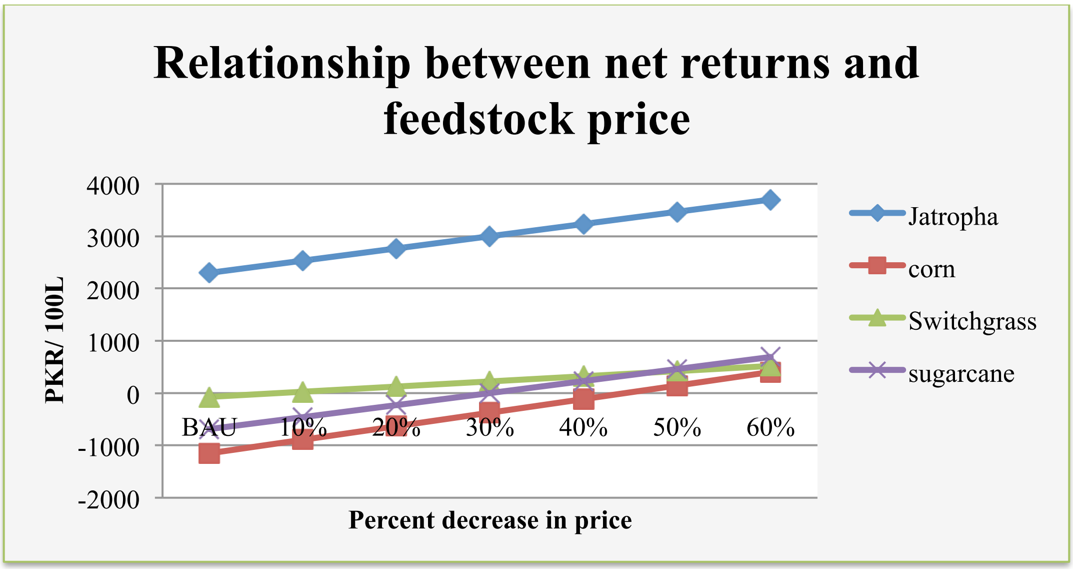


Fig. 9: Sensitivity analysis to check the breakeven price of feedstock

6.2. Comparative analysis of biofuel feedstocks

A comparison of costs, benefits and net benefits is presented in **Table 11**, which shows that among all the projects, costs of production (opportunity costs) were highest for corn followed by jatropha and sugarcane. However, benefits that were, in fact, the prices of biodiesel and biofuel, were similar for corn, switchgrass and sugarcane because these feedstocks generated bio-ethanol while jatropha produces biodiesel. Therefore, biodiesel prices were taken as benefits.

Table 11: Costs, benefits and net returns versus benefits-costs ratio of all biofuel projects, PKR/100 litres

	Benefits	**Costs**	**Net benefits**	**Benefits/costs**
Jatropha	4603.4	2315.6	2287.7	1.99
Corn	1924.7	3072.4	-1147.7	0.63
Switchgrass	1949.9	2021.2	-71.3	0.96
Sugarcane	1927.3	2619.2	-692.0	0.74

It was assumed that all the biofuel production projects (that vary in input use) were independent such that adoption of one did not have any impact on the costs and benefits of others. In this case, CBA's decision rule, as mentioned by Boardman *et al.* (2006), is *"to adopt all policies that posses positive net returns"*. In the current scenario, net returns were positive only for jatropha whereas for biofuels there was a negative trend. Thus, the feasible and efficient choice was to adopt only jatropha-based biofuel.

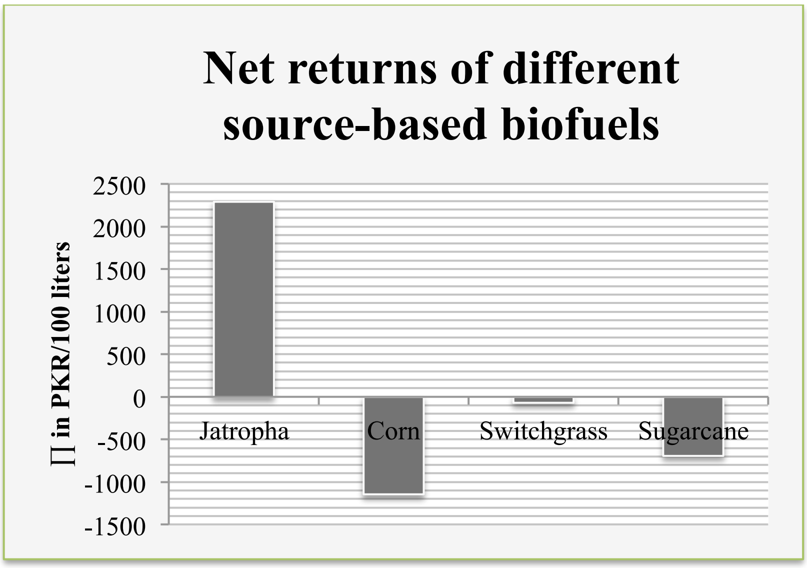


Fig. 10: Comparative analysis of net returns, PKR/100 litres

Another criterion on the basis of which analysts can choose the projects is the 'benefits to cost ratio' (**Table 11,** 5th column). This ratio also suggested the selection of jatropha project, in accordance with net benefit criteria. An assessment of only the net returns yielded by biofuel technologies has shown that among the negative net benefits, switchgrass encompasses the lowest negative net benefits followed by sugarcane and corn (**Fig. 10**).

On the other hand, it can be seen that the international price for biodiesel is very high relative to ethanol price (**Table 9**). For this reason, biodiesel price can cover the costs of production but ethanol price may lack this ability. Thus, huge variation in the net returns of bioethanol and biodiesel can mainly be due to very high international biodiesel prices and relatively low prices for ethanol.

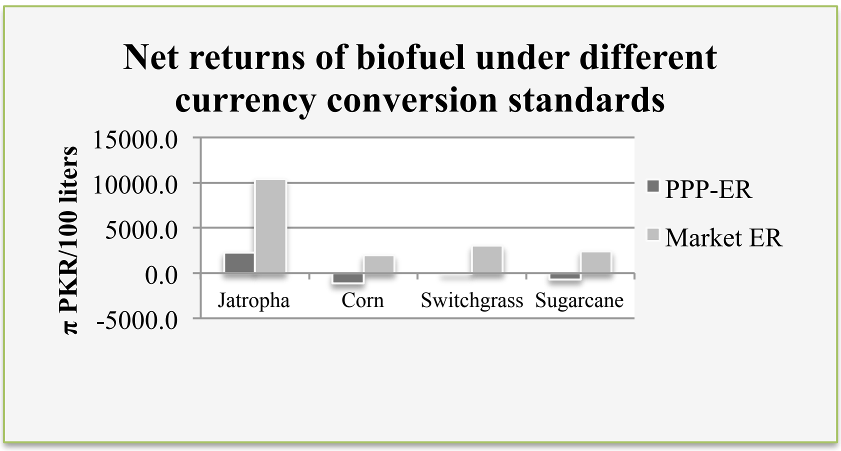


Fig. 11: Net returns under PPP exchange rates (ER) and market ER

Secondly, currency conversion was made using PPP-exchange rates. PPP-exchange rates are less than half of the market-based exchange rates. Net returns for all feedstock became higher when market-based exchange rates were applied (**Fig. 11**).

6.3. Risk and net returns

To calculate risk, Monte Carlo simulation was adopted and 500 repetitions were performed using Microsoft excel. The statistical results (mean and variance of net returns) generated by this simulation were then plotted in a graph which has shown that only one production technology (jatropha) was associated with a high level of risk. On the other hand, corn, switchgrass and sugarcane were nearly equally risky (**Fig. 12**).

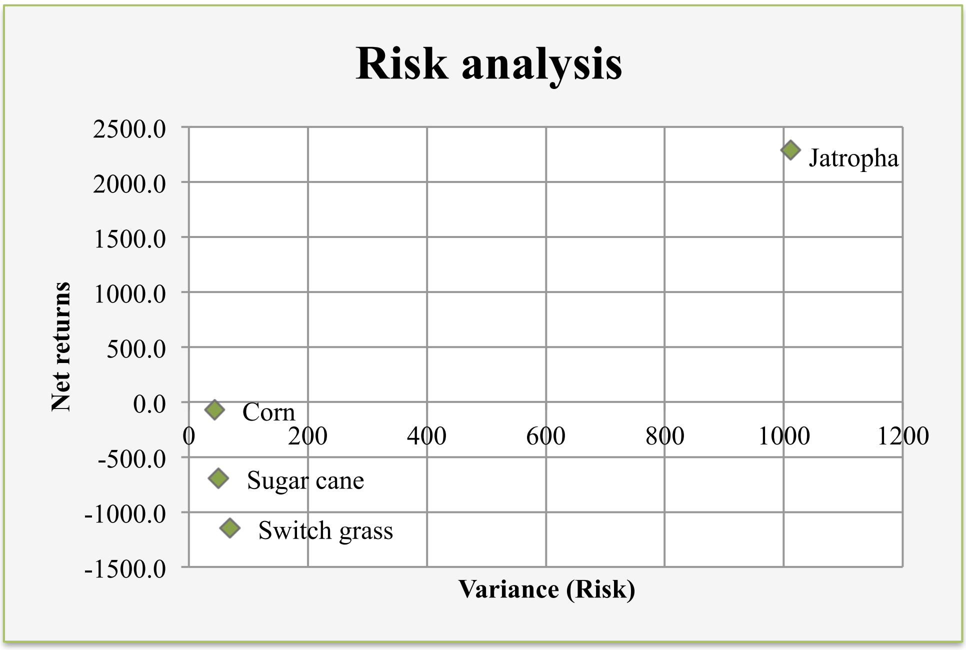


Fig. 12: Risk analysis of biofuel production technologies

As it was anticipated in the theoretical section that high net returns might be associated with higher risk, the results satisfy the theory. This indicates that the jatropha production technology with high returns is the riskiest. However, biofuels with negative returns still possess risk. The level of risk increases as the negativity of net returns decreases.

6.4. Other choices under uncertainty

This section will discuss how the decisions are taken in different ways under uncertainty. For this purpose, the following rules were applied:

1) Maximin rule
2) Maximax rule
3) Minimax regret rule
4) Best-worst choices

The payoff matrices (consisting of minimum and maximum net returns) are given for all the rules (**Table 12, 13 & 14**). The method of matrix construction and choice of strategies under different rules were also discussed as follows:

Table 12: Net returns in PKR/ 100 litres for Maximin and Maximax rule

	Min	Max	Average	Minimum payoff	Maximum payoff
Jatropha	2609.3	2012.3	2287.7	**2012.3**	**2609.3**
Corn	-1252.5	-1025.9	-1147.7	-1252.5	-1025.9
Switchgrass	-401.3	229.2	-71.3	-401.3	229.2
Sugarcane	-894.9	-466.0	-691.9	-894.9	-466.0

1) ***Maximin rule:*** minimum, maximum and average net returns of all alternatives (biofuels) (as computed empirically) were stated in **Table 12**, under the strategies of Max, Min and average. If the producer feels that minimum net returns are more likely to happen, he tries to maximize the minimum net return. From Min, Max and average strategies, the minimum payoffs are given in the second-last column of **Table 12**. The biggest net returns among all the given minimum payoffs is 2012.3 (yielded by jatropha) which is hoped to maximize the minimum net returns (of all biofuel types). Thus, jatropha is selected under this criterion.

2) ***Maximax rule:*** as given in table 12, an optimistic biofuel producer who wants to seek highest profits, comes across the maximum payoffs of 2609.3, -1025.9, 229.2 and -466.0 from jatropha, corn, switchgrass and sugarcane, respectively (**Table 12**). He/she selects jatropha-based biofuel which is the best option out of all the given maximum net returns.

Table 13: Net returns for Minimax regret rule

	Min	Max	Average	Maximum Regret
Jatropha	0	597	321.6	597
Corn	226.6	0	121.8	**226.6**
Switchgrass	630.5	0	300.5	630.5
Sugarcane	428.9	0	225.9	428.9

3) ***Minimax regret rule:*** for the purpose of selection under this rule, a regret matrix (**Table 13**) was calculated, by suitable changes in table 12. This was performed by selecting the higher profits for all source-based biofuels and then the regrets were calculated as the deviation from the higher outcome. From the given maximum regret (last column of Table 13), Minimax regret rule favours biofuel produced from corn which generates minimum regret. The aim is to leave the alternatives, which have most costly mistakes.

4) ***Best-worst choices:*** due to uncertainty in net returns, exchange calculations of costs and benefits were made to acquire the best-worse choices. In this regard, worst choices were calculated by deducing Max cost from Min benefits (Min B - Max C) and the difference of Max benefits and Min costs (Max B - Min C) were considered the best choices (**Table 14**).

Table 14: Matrix for Best-worst choices

	Worst net returns	Best net returns	Original net returns
Jatropha	-18.2	4639.8	2287.7
Corn	-1761.1	-517.2	-1147.7
Switchgrass	-506.1	333.9	-71.3
Sugarcane	-1201.2	-159.6	-691.9

The results under best and worst scenarios remained significantly different with 'Best-worst choices' (**Table 14**). Most prominently, net profits of jatropha were turned negative in the worst case. In the best net return choices, positive net returns became even better and negative net returns were also improved compared to the original case. Under the worst case, although net returns had grown worse yet the order of negative net returns for different biofuels remained unaltered. This trend is in accordance with original results; corn yielded lowest net returns, which was followed by sugarcane and switchgrass. To sum up, 'Best-worst choices' selects production of jatropha and switchgrass biofuel under best case but do not favour production of biofuel when worst scenario happens.

Decision making criteria in the presence of uncertainty came up with the selection of jatropha (Maximin rule, Maximax rule and Best-worst choices), corn (Minimax regret rule) and switchgrass (Best-worst choices); however, none of the measure selected sugarcane.

Adoption of recommended strategies may reduce uncertainty in net profits. However, the choice of any method under uncertainty entirely depends on the nature of the investor and his attitude in making profit and volatility in returns.

7. Conclusions and discussion

The study aimed at analyzing the net returns and production risks of selected feedstock-based biofuels. In this regard, switchgrass, jatropha, corn and sugarcane were selected from a wide variety of favourable feedstocks. The costs and benefits of fuel conversion of each feedstock were evaluated using standard cost benefit analysis.

The net profits generated by jatropha were positive while other feedstocks yielded negative net returns. Therefore, if only private net returns are of interest, only jatropha based biofuel is recommended to produce which exhibits positive net returns of 16.8 PKR/litre or 0.47 USD/litre. In principle then, if the net return is sufficient for covering fixed costs jatropha would not need governmental support. This is not the case with the other biofuel projects, as they yielded net returns of -12.9, -2.5 and -9.21 PKR/Litter or -0.36, -0.07 and -0.26 USD/litre, respectively. These biofuel options are implemented only if governmental support covers the negative returns plus fixed costs. Whether or not support should be paid depends on the level of the positive externalities, such as environmental benefits and energy security. However, risk analysis reflected that feedstocks with high returns were associated with high risk. Therefore, jatropha-based biofuel was proved riskiest biofuel while other biofuels possessed almost same level of risk.

It is believed that negative net returns are mainly influenced by feedstock prices. About 57.6% and 36.4% of total inputs consist of feedstock in FGF and SGF, respectively (Eggert *et al.* 2011). Since there is a requirement of large proportion of feedstock, as a raw material, for fuel conversion and prices of agricultural products are high, the cost becomes higher. These high costs are particularly crucial for corn as it is a food item. Though it enjoys technically efficient production scales, yet cost of fuel production is still very high. On the other hand, switchgrass and molasses are currently on the earlier stages of technical advancements and require cost reduction on agro-farm levels. In support of this conclusion, several studies have also not recommended the production of biofuel, based on the reason of high expenditures (Chakrabarti *et al.,* 2011; Carriquiry *et al.,* 2011). Analysis performed on breakeven price in section 6.1 suggested the need to substantially decrease prices of raw material. Reduction in these prices will facilitate the economical production of biofuels.

The jatropha biodiesel yielded positive net returns and is therefore considered suitable for implementation in the industry. The final benefits of jatropha biodiesel can compensate for the cost of production because feedstock can be cultivated on marginal and wastelands with relatively lower expenses. Thus, this type of biodiesel production is based on low priced and easily grown raw material. Moreover, biodiesel prices are high in the international market, which makes the benefits as high as to cover the cost of production. However, there are some reports that do not support the production of jatropha biodiesel (Wang *et al.,* 2011) while others recommended the production (Chakrabarti *et al.,* 2011). In the latter case, recommendations were made based on the comparison among different feedstocks for biodiesel production. In the former case, few reservations, such as over-estimated yield of jatropha biodiesel on wasteland, surpass the positive side of jatropha. Similarly, Findlater and Kandlikar (2011) stated that although jatropha showed great resistance to drought and climatic conditions, yet plant growth and seed yield were reduced substantially.

Net returns depend on how and which of the factors are included in the cost and benefit analysis. On the one hand, the benefits of biofuel comprise of only prices of ethanol and biodiesel. Such benefits are devoid of all the environmental and social impacts in monetary terms. Therefore, it is not sufficient to cover the cost of production. On the other hand, cost comprises of variable costs excluding fixed costs which also understates costs. If all the fixed and variable costs were combined, the gap between benefits and costs would have been even wider. Also, by including all the costs and benefits of biofuels, the results would have been different from that suggested by this study.

In recent times, the biofuel industry has been heavily supported by policies to enhance self sufficiency in alternative fuel. Eggert *et al.* (2011) provided a comprehensive guide to the combination of policies in the form of tax, subsidies, direct funding, standards, R&D funds etc. given by the US, the EU, Brazil and China to their biofuel industry. Conclusions of the present study also support the provision of policy support. Since, this action can, at one place, be helpful in the implementation of corn, switchgrass and corn based biofuel, however, it can make net profits of jatropha based biofuel extra ordinary (supernormal profits).

Risk analysis conducted in this project demonstrated that biofuels with higher net returns are riskier. As mentioned earlier, key risk elements include feedstock deficiency, price change, input price, process and storage, equipment malfunctioning, and shortage of key utilities among others. To proceed successfully, producers have to either control the risks or reduce the risk and its impacts on production. For the purpose of mitigating impact, management practices should be improved. If the investor is interested in reducing risk in biofuel production, technological advancement could be helpful. Another alternative is to transfer the risks to someone else by contracting and insurance.

The model particularly takes into account four feedstocks to possibly avoid the food versus fuel issue. Corn and sugarcane belongs to the 1st generation biofuel category. On the other hand, switchgrass and jatropha belong to the 2nd generation biofuels. However, based on the analysis performed in this study, sugarcane can also be regarded as a 2nd generation biofuel. This is due to the fact that biofuel generation requires only the molasses, not the whole sugarcane, which is mainly used for industrial purposes. In this sense, only corn is subjected to the food versus fuel debate.

Although, the analysis in this study was performed based on Pakistani perspectives, results will provide foundations for directions and pathways to generate biofuels in many developing countries with similar climatic and sociocultural status. Transformation of costs and benefits estimates from different countries was carefully done and necessary changes and adoptions were made. However, to use results from this study for future references and research, it is crucial to follow the assumptions stated in section 5. Data regarding cost of conversion also requires further assessment. For reliable and valid data, an extensive survey is required according to the circumstances of Pakistan.

Owing to the many economic, environmental and social merits and demerits of mineral fuel, and 1st and 2nd generation biofuels, a higher stress should be given on the technological innovation and production of 2nd generation biofuels. In Pakistan, there lies high potential in promoting non-food biofuels. Currently, Pakistan is facing a fuel crisis, depending heavily on imported fuel and undergoing financial problems. Despite these facts, the government and public are keen to develop and promote sustainable sources of energy. In this respect, the country should seek international cooperation and technical knowledge to resolve its energy crisis.

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