Abstract

Pakistan is a developing country which is faced by the scourge of energy deficiency. The country is dependent upon the import of oil for energy as it does not have ample resources of oil. The energy crises along with the heavy costs of importing the oil, produce immense pressure on the country's economy. During the fiscal year 2012-2013, the transport sector of the country has 49.57% share in the total consumption of oil. Approximately 1794 million liters of gasoline was consumed by this sector in 2012. In this paper, the potential for ethanol production and its substitution in Pakistan is found. The results are focused on sugarcane production, demand for sugar, economic growth for the country and potential reduction in carbon emissions. Currently there is a potential of 274 million liters annual ethanol production, without affecting the production of food products from sugarcane. The transport sector can be benefited from ethanol after it is blended with gasoline under four different scenarios, which will lead to the minimization of gasoline consumption and subsequently the associated economic and environmental effects. […]

Reference

ABSTRACT
Pakistan is a developing country which is faced by the scourge of energy deficiency. The country is dependent upon the import of oil for energy as it does not have ample resources of oil. The energy crises along with the heavy costs of importing the oil, produce immense pressure on the country’s economy. During the fiscal year 2012-2013, the transport sector of the country has 49.57% share in the total consumption of oil. Approximately 1794 million liters of gasoline was consumed by this sector in 2012. In this paper, the potential for ethanol production and its substitution in Pakistan is found. The results are focused on sugarcane production, demand for sugar, economic growth for the country and potential reduction in carbon emissions. Currently there is a potential of 274 million liters annual ethanol production, without affecting the production of food products from sugarcane. The transport sector can be benefited from ethanol after it is blended with gasoline under four different scenarios, which will lead to the minimization of gasoline consumption and subsequently the associated economic and environmental effects. Results indicate that the best possible blending ratio can be E8 in the present and the predicted situation. In addition to that, the usage of ethanol will add to a positive environmental impact by reducing 14.6 million tons of CO₂ emissions by 2030. Finally, the substitution of ethanol over gasoline will lead to lower imports of oil products, thus reducing the cost and less draining of resources from the Pakistani economy. This method, if implemented, can provide an incentive for improved yields in sugarcane production and help develop the industrial sector. The outcomes of this paper may also be followed and similar techniques may be implemented by other developing countries having alike resources.

Keywords: Ethanol, Gasoline, Sustainable Transportation, Carbon Emissions, Pakistan

INTRODUCTION
Pakistan is engulfed in severe energy crises that have put an immense pressure on its economy. The country is heavily dependent on the usage of fossil fuels especially oil for energy production. Almost 40% of the total imports of the country is comprised of oil [1]. The transportation sector is also a major contributor to the total oil consumption of the country in the form of gasoline, diesel and liquefied petroleum gas (LPG). The transportation sector consumed around 49.57% of the total oil consumption in the year 2012-2013 [2].

Gasoline consumption for the country was around 1435 million liters in the year 2012. The country has not sufficient oil reserves and is dependent upon oil imports for consumption which produces enormous burden on the country’s economic growth. For the sake of sustainable development, it is essential to switch to alternate resources for substituting oil products such as gasoline with gasohol. Gasohol is an alternate fuel comprises of ethanol fuel blended with gasoline in different ratios. This paper presents an analysis regarding suitable percentage of ethanol to be substituted over gasoline for transportation in Pakistan.

Fuel ethanol is being produced in several countries, which include Brazil, United States, China and India [3]. Global production of bio-ethanol rose from 17.25 billion liters in 2000 to more than 46 billion liters in 2007 [4]. The largest producer is the United States which produced around 52,118 million liters millions gallons of fuel ethanol in 2012. Brazil is among the pioneers that have substituted ethanol for gasoline. It produced around 21,111 million liters of fuel ethanol in 2012 [5]. Brazil initiated the program named as National Alcohol Program in the year 1975, which aimed at saving the country’s foreign exchange by substituting alcohol for fuel. The program focused on increasing net supply of foreign exchange by decreasing imports of fuel, improving agricultural income and increasing national income and domestic capital goods’ growth [6]. In 1993, the government of the country decided to blend all gasoline market by 20–25% [4]. In 2003, the country introduced Flex Fuel Vehicles (FFV) which can utilize mixtures of alcohol and gas as fuels. Thus the consumers have the liberty to react to fluctuating prices of both markets. In the beginning of 2005, the sales of FFVs were higher than gas vehicles and contributed to 57% of the total vehicles sold [6]. Between the years 2004–2009, the production of automobiles in the country having flex fuel capability increased from 30% to 80% [4]. In Brazil, fuel ethanol is blended with gasoline to prepare gasohol (24% ethanol, 76% gasoline) [7].

The US Clean Air Act Amendments in 1990 were the first to consider fuels for emission reductions along with vehicle technology. They focused on increasing oxygen content of gasoline and ethanol has been used as an oxygenate and also as a major fuel component since then [7]. Ethanol can be used as oxygenate because it has 37% oxygen content by weight. This boosts the fuel combustion, which in turn leads to reduced use of petroleum,
contributing to lessening of emissions [8]. Globally 60% of bioethanol production is done by sugarcane and 40% from other crops. Brazil uses sugarcane for the production of bio-ethanol; the US utilizes corn while wheat and barley are being used by Europe [4]. As biofuels are an attractive option for sustainable development, policymakers around the world have initiated suggesting a certain percent of ethanol sold in future. In 2007, the US Department of Energy announced $1 billion to be invested in biofuels in future. The EU has announced to reach a goal of 10% for the replacement of fuels used in transportation. In 2007, Canada also announced $1.5 billion to be invested in renewable energy over the next 9 years and emphasized on a 5% renewable content in gasoline by 2010 [9]. These factors have given rise to ethanol production globally.

While the developed countries are shifting to biofuels, research has also been conducted in developing countries for fuel ethanol production. According to a research, Nepal has the capacity to produce 18,045 million liters of ethanol annually, using sugarcane, without affecting the production of food products. The country has no fossil fuel reserves and is dependent upon imports. The transport sector of the country is the biggest user of petroleum products. The Kathmandu valley comprises of 30% of the total population of the country, having 56% of the total registered cars in Nepal and accounts for 70% of the total consumption of imported gasoline. Nepal lies in the South-Asian region, joining borders with India. Thus, like its neighbors, Nepal is also an agricultural country. The current scenario of producing 18,045 m³ of fuel ethanol in the country would help offset the 7.4 million liters of gasoline being consumed in the Kathmandu valley [10].

The idea to reduce emissions from vehicles also encouraged India to contribute in this regard. The government of India initiated three projects in the country in 2001 which allowed 5% blending of ethanol with gasoline only to retailers [11]. By 2007, the sugar industries in India were producing 1.3 billion liters of ethanol annually [8]. In November 2012, the government mandated a blend of 5% ethanol in gasoline and an optional blend of 10% blending. By the year 2017, the country aims to achieve 20% blending across the country [11].

Pakistan has also taken some measures to introduce fuel ethanol in the country. The government of Pakistan set directions in 2006 to blend 5% ethanol in gasoline to be utilized for vehicles, to reduce the oil imports of the country [12]. Pakistan State Oil (PSO) also initiated blending of ethanol in gasoline in a ratio of 10% in 2009. The product was named E10 and it focused on promoting renewable energy resources and reducing greenhouse gas emissions, along with reduction in imports and providing economical fuel to the people [13].

Pakistan is also utilizing natural gas, in the form of CNG (Compressed Natural Gas) since 1992. According to the statistics of the Association of Natural Gas Vehicles, the country had the highest number of vehicles running on CNG, approximately 3.1 million by December 2008 [14]. By the year 2010-11, the number of vehicles raised up to more than 3.5 million which was around 21% of the total vehicles running in the country [15]. Due to this overconsumption of reserves, the CNG is unavailable to the consumers for some days of the week. The government has made policies to perform ‘load-shedding’ of CNG on certain days of the week, to avoid exhausting of the resources. Therefore the motivation for this research comes from the ongoing energy crises, economic instability, social issues and increased pollution levels currently faced by Pakistan. This work builds directly on the research performed by [12] such that,

- Existing research contains the potential for ethanol production from sugarcane produced per annum without considering the sugar demand in the country. This research takes into account potential production of ethanol without compromising the sugar needs for the country.
- Literature contains details regarding different ethanol blending scenarios to gasoline, without modifying the vehicular engines. In this research, similar scenarios are compared against the demand of gasoline bringing economic stability and suitable scenario has been proposed at the end.
- This research also contains the potential reduction of carbon emissions that may be achieved for the proposed blending scenario discussed till 2030 thus mitigating climate change.

This paper will proceed by first discussing the salient features of transportation sector of Pakistan followed by sugarcane growth patterns in the country and potential for ethanol production in the country. Next section continues with analyzing different blending scenarios and their projections to come up with a suitable blend possible considering several constraints. Last section focuses on potential reduction in carbon emissions by substituting ethanol as a fuel in the country followed by conclusions and recommendations at the end.

**SALIENT FEATURES OF TRANSPORTATION SECTOR OF PAKISTAN**

A short abstract should state briefly the content, methods and results only. Define abbreviations and acronyms the first time they are used. Avoid footnotes at the bottom of the page within the frame.

**Fuels Available for Transportation**

Only 18% of the total demand of petroleum products is met through local resources and the remaining 82% is covered through imports [16]. The imported crude oil was around 18 Mtoe in the year 2012 [17]. The transportation sector of Pakistan has different types of fuels available for utilization. These include Natural Gas, Gasoline, HSD (High Speed Diesel) and Jet Fuel. Diesel contributes to the major consumption, followed by natural gas, gasoline and jet fuel respectively. In 2007, diesel contributed to around 69.62% of the total fuel consumption by the transportation sector while natural gas, gasoline and jet fuel consumed approximately 22.78%, 5.06% and 2.53% respectively of the total fuel consumption. In 2012, the consumption patterns reformed and a significant change was observed in natural gas and gasoline percentages. [17]. Table 1 shows the contribution of
each fuel in the total fuel consumption in 2012. The logical reason for the reduction in natural gas and the increase in gasoline percentages is the CNG load shedding which force the consumers to opt for gasoline.

Table 1. Contribution of different fuels in the total fuel consumption of Pakistan in 2012

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Contribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>67.86</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>15.5</td>
</tr>
<tr>
<td>Gasoline</td>
<td>14.3</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>2.4</td>
</tr>
</tbody>
</table>

**Fuel Demand Patterns**

As stated earlier that the transportation sector of the country is one of the biggest consumers of oil. It contributed to around 49.57% of the total oil consumption in the country, having a 5.3% increase in the year 2011-12 [2]. Gasoline and diesel constitute the majority of total fuel consumption, having a cumulative share of around 77%. As described above, the demand for fuel in transport sector is increasing annually. The transportation sector consumed around 7.9 Mtoe of fuel including Natural Gas, Gasoline, Diesel and Jet Fuel in the year 2007 and it increased to around 8.4 Mtoe in 2012. It is anticipated that the fuel consumption would be increased to around 19 Mtoe by the year 2030 [17].

**Patterns of Passenger Transport**

Pakistan’s transport system includes roads, railway, air traffic and shipping. The road network in the country accommodates around 96% inland freight and 92% of the total passenger traffic and serves as a backbone to the economy of the country. The road network is approximately around 263,415 km. National highways are around 3.5% of the total, corresponding to 9234 km. Apart from that, the country has a few motorways, having a total 2280 km and corresponding to 0.87% of the total road network. Strategic roads are around 263 km and Expressways are nearly 100 km in total. The rest of the road network comprises of roads under local administration [18]. There is a variety of vehicles that use the road network. These constitute of cars, buses, trucks, mini vans, rickshaws etc [17].

**ETHANOL PRODUCTION POTENTIAL OF PAKISTAN**

**Sugarcane Production**

Pakistan is an agricultural country and a large producer of sugarcane. Pakistan ranks 5th in the world for sugarcane production [19]. The country produced around 62.5 million tons of sugarcane in the year 2012–2013 [20] and has an annual average production of around 55.41 million tons [19]. The production of sugarcane in the country has kept an average increase of 5.8% annually between the years 2010–2013 [2]. Pakistan is also the 12th largest producer of sugar in the world. There are 84 sugar mills in the country and after textile, it is the largest industry of the country [21]. The sugar demand for country is estimated to be around 4.5 million tons in the year 2012 [22]. The country has an enormous potential of producing ethanol even without compromising the sugar needs of the country. This produced ethanol can be used to offset the increasing gasoline demand.

**Ethanol Production**

The production of molasses from sugarcane is around 4% of the total sugarcane. In addition to that, from one ton of sugarcane, approximately 120 kg of sugar can be obtained after processing [23]. Approximately 270 liters at an average can be recovered from 1 ton of molasses [12]. This means that approximately 37 million tons of sugarcane is required to meet the country’s demand. If the demand of the country is not to be compromised, then approximately 24.51 million tons of sugarcane is being produced in excess and can be used for the production of ethanol which can further be used as a blend in gasoline. According to the stoichiometric ratio discussed above, one ton of sugarcane can produce up to 270 liters of ethanol, so 24.51 million tons of excess sugar cane may be used to produce around 274 million liters of ethanol annually. The demand for gasoline was around 1435 million liters in the year 2012 [17]. This suggests that, if the required food products from sugarcane stay same, ethanol can offset 19.1% of gasoline consumption annually in the current scenario.

**Substituting Gasoline with its Blends**

The gasoline demand in the country is increasing rapidly due to shortage of natural gas. It is estimated that the demand for gasoline would reach to around 6938 million liters by 2030 [17]. Pakistan had a sugar demand of around 4.5 million tons in the year 2012 [22]. Figure 1 indicates the projections of potential ethanol production in Pakistan from 2012–2030. The projections are done while considering no compromise on sugar demand of the country for all the years and considering annual growth of sugarcane considering the past patterns.

Gasoline can be blended with ethanol in different ratios, while making no change in the engine of the vehicle. This suggests that, vehicles can utilize different blending ratios of ethanol in gasoline without affecting their performance. In this research, five different scenarios are considered and are shown in Table 2. Considering all the blending ratios, gasoline demand projection from the year 2012 to 2030 is presented in Figure 2. As expected, it is evident from the figure that the curve for gasoline demand shifts downward as the blending ratio increases.
Table 2. Blending ratio of ethanol into gasoline and its energy content

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Ethanol Blended (%)</th>
<th>Calorific Value (MJ/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Blending</td>
<td>0</td>
<td>32.19</td>
</tr>
<tr>
<td>Minimum Blending</td>
<td>5</td>
<td>31.63</td>
</tr>
<tr>
<td>Low Blending</td>
<td>8</td>
<td>31.31</td>
</tr>
<tr>
<td>Moderate Blending</td>
<td>10</td>
<td>31.09</td>
</tr>
<tr>
<td>High Blending</td>
<td>15</td>
<td>30.54</td>
</tr>
<tr>
<td>Maximum Blending</td>
<td>20</td>
<td>29.99</td>
</tr>
</tbody>
</table>

Figure 1. Ethanol production estimate for Pakistan with projection up to 2030

Figure 2. Gasoline demand reduction projections with different ethanol blending ratios from 2012 – 2030

The estimated projection indicates that the country would have the potential to produce around 563 million liters of ethanol annually by the year 2030. The results also conclude that if ethanol is substituted for a ratio of 8%, the ethanol production potential would be sufficient to fulfill the gasoline demand by 2030. However, for ratios greater than 8%, the ethanol required to be blended would be greater than the potential of the country. For this research, the best possible blending ratio is found to be E8.

Figure 3. Gasoline demand of Pakistan & its potential reduction if all the ethanol being produced is used for fuel substitution

Figure 3 demonstrates the potential reduction in gasoline demand of Pakistan while considering the case where all the ethanol being produced in the country is utilized to offset the amount of gasoline being used. The trend indicates that Pakistan has the potential to save around 563 million liters annually, if all the ethanol being produced is substituted for fuel in vehicles.
MITIGATING CLIMATE CHANGE BY INTRODUCING GASOHOLS

Pakistan is a densely populated country. The country has a current population of around 184.35 million [24]. The country has high levels of pollution especially in the urban areas. The dust and smoke particles are around five times higher than the developed countries. The number of vehicles running in the country has increased 5 times in the last two decades. The increase in vehicles is concentrated on two-stroke vehicles and vehicles burning diesel, which are among the most polluting types of vehicles. In addition to all that, the consumers use cheap, inefficient and highly polluting fuels to meet their demands [25]. This poses a serious threat to the country and approximately 2500 people die each year due to emissions from vehicles in the country [14]. Since the results recommend that E8 is the best possible scenario for gasoline substitution in Pakistan, so the amount of carbon emissions reduced by using 8% blending ratio of ethanol can also be calculated that can be proved advantageous for mitigating climate change. Equation 1 and 2 show the combustion of gasoline and ethanol respectively;

\[ 2\text{C}_8\text{H}_{18} + 25\text{O}_2 \rightarrow 16\text{CO}_2 + 18\text{H}_2\text{O} \]  
\[ \text{C}_2\text{H}_5\text{OH} + 3\text{O}_2 \rightarrow 2\text{CO}_2 + 3\text{H}_2\text{O} \]

From stoichiometry, amount of carbon dioxide produce can easily be determined to compare against the two scenarios of no blending and blending 8%. Figure 4 illustrates the potential reduction in CO\(_2\) emissions by substituting the suggested percentage of ethanol over gasoline in Pakistan. The results display that around 14.6 million tons of CO\(_2\) can be reduced by the year 2030.

![Figure 4. CO\(_2\) emission reduction by introducing gasohol with a blending ratio of 8%](image)

CONCLUSION

There is a significant potential of ethanol production from molasses in the country without compromising its own sugar needs. Ethanol, being a renewable, economic and environmental friendly fuel, can be used after blending with gasoline in different ratios in the transportation sector bringing stability to the ongoing energy crises that has swamped Pakistan. For ratios more than 8%, the ethanol required to be blended would be greater than the potential of the country. Therefore, the best possible blending ratio is proposed to be E8. In this way, millions of dollars could be saved by reducing oil imports. Introducing gasohols can not only serve as a building block towards sustainability but also bring environmental and health benefits for the country.

REFERENCES


