FACTOR ANALYSIS FOR PROMOTING BIOENERGY: LESSONS FROM INTERNATIONAL EXPERIENCES FOR ALBERTA

by

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B.Sc., Gachsaran Islamic Azad University, 2005

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ABSTRACT

Alberta is a resource abundant province and with more than 38 million hectares of forest land (more than 60% of the province land), it has a considerable potential of bioenergy resources. While the annual wood production capacity is 24 million cubic meters of wood, the province has imported more than 90% of its bioenergy consumption. This project seeks to identify the main factors that can help promoting bioenergy industry in Alberta. Econometrics and time series analysis are used to quantitatively measure the impacts of different factors in facilitating the penetration of bioenergy technologies within the energy system. Results of the modelling based on the advances in pioneering countries suggests that availability of bio-resources, structure of the energy sector and also price of energy are the most decisive factors that affect the penetration rate of bioenergy. Considering these dominant factors, the barriers for bioenergy production in Alberta are investigated.

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Abbreviations

ANBP	Alberta Nine-Point Bioenergy Plan
BEP	Bioenergy Potential
BIDGP	Bioenergy Infrastructure Development Grant Program
BIND	Bio-Industrial Network Development
BRFS and MT	National Renewable Fuel Standard and Energy Market Targets
CMDP	Commercialization/Market Development Program
CPI	Consumer Price Index
EC	Environmental Concerns
EP	Energy Price
EPC	The Per Capita Energy Consumption
FAO	Food and Agriculture Organization of the United Nation
GDP	Gross Domestic Product
GHGs	Greenhouse gas
IEA	International Energy Agency
ISBP	Investment Support Through Existing Programs That Align With Bioenergy Development
MSPR	Energy Micro-generation Standards and Policy Revisions
MSW	Municipal Solid Waste
OECD	The Organization Of Economic Co-operation Development
RE	Renewable Energies
REPCP	Renewable Energy Producer Credit Program

SRM	Specified Risk Material
SRMDP	Specified Risk Material Disposal Protocol
TIIBS	Taxation and Investment Instrument For the Bioenergy Sector
UNECE	United Nation Economic Commission for Europe

DEDICATION

To my Family.

Chapter 1

Introduction and Objectives

1.1 Background

Biomass feedstocks such as agricultural and forestry products and residues, industrial and municipal bio-waste, animal waste and landfill gas are used for bioenergy production (Table 1.1) [1-5].

Table 1.1: Bioresources for bioenergy production [1-5]

Agricultural crops and byproducts	Oilseed and starch crops (canola, wheat, corn) Straw and waste (straw, husk) Non-food crops (camelina, carina, energy crop)
Forestry	Fast growing species Non-merchantable residue (forest residue) Processing waste (sawmill residue)
Animal co-products	Manure Animal processing waste (tallow)
Municipal and commercial wastes	Municipal Solid wastes Bio-solids Commercial and Industrial wastes

As a source of energy, biomass feedstocks are used to produce heat, electricity, transportation fuel and synthetic natural gas (Figure 1.1) [4, 6-8].

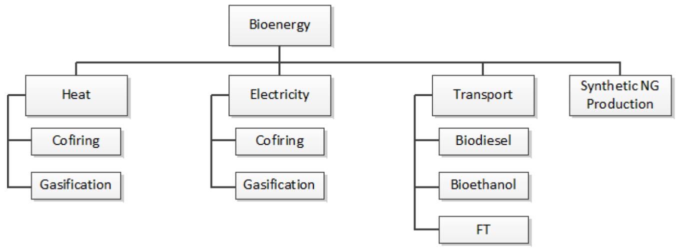

Figure 1.1: Bioenergy Production Routes

Despite the considerable bioenergy potential worldwide [9-12], the penetration rate of bioenergy varies in different countries [13]. In the last quarter of 20th century, the use of forest bioenergy doubled in Sweden. In neighboring Finland, bioenergy now accounts for 7.9% of the fuel mix in district heating [15, 16]. The forces that lead to these differences are not well understood [14]. The penetration of alternative sources of energy within an energy system is affected by several factors including local potential for the alternative technology, techno-economic feasibility, and socioeconomic and environmental constraints [15-23]. While some of these factors facilitate the penetration of alternative energies (e.g. locally available potential and environmental regulations), others are hindering factors which slow down the adoption process (e.g. economic feasibility). Policy instruments are tools to enhance the promoting factors and eliminate the hindering factors for bioenergy adoption in the energy system [15, 18, 21, 22]. However, there are a few studies which quantify the cause and effect relationship between policy instruments and the adoption rate of bioenergy.

1.2 Objective

This report seeks to identify drivers of bioenergy and assess the effectiveness of policy measures for promoting bioenergy in the energy system. More precisely, key factors which affect adoption of bioenergy technologies in the system are identified and the importance of each factor in promoting bioenergy in the system is assessed. In the second part of the study, applicability of the identified policies for the province of

Alberta, Canada, is investigated. By localizing the effective bioenergy supporting policies for Alberta, the deficiencies of current provincial policies are analyzed.

The structure of the report is as follows: overview of bioenergy in Alberta will be provided in Chapter 2. This includes, analyzing the current status of bioenergy in the province, the ultimate potential for bioenergy and the existing governmental policies to support bioenergy. Preliminary results of literature review for identifying the key drivers of bioenergy in the world are provided in Chapter 3. Chapter 4 describes the statistical modeling and its results for bioenegry promotion. Chapter 5 localizes these results and discuss the deficiencies in Alberta policy for bioenergy adoption. Chapter 6 will provide the concluding remarks. Conclusions and recommendations are provided in Chapter 7.

Chapter 2

Bioenergy in Alberta

2.1 Current Status

In Alberta, the total average annual production of wheat, barley and oats and forest residues during the time period between 1997 and 2008 has been 6.8, 6.3, 0.72 and 4.27 million tonnes per year, respectively [5, 24]. The total forest land in the province covers 38 million hectares (i.e. 60% of the province land) with the potential for producing more than 24 million cubic meters of wood annually [5]. Provincial availability of different bioenergy feedstock including agricultural residues, forest products and residues and municipal solid waste (MSW) is summarized in Figure 2.1.

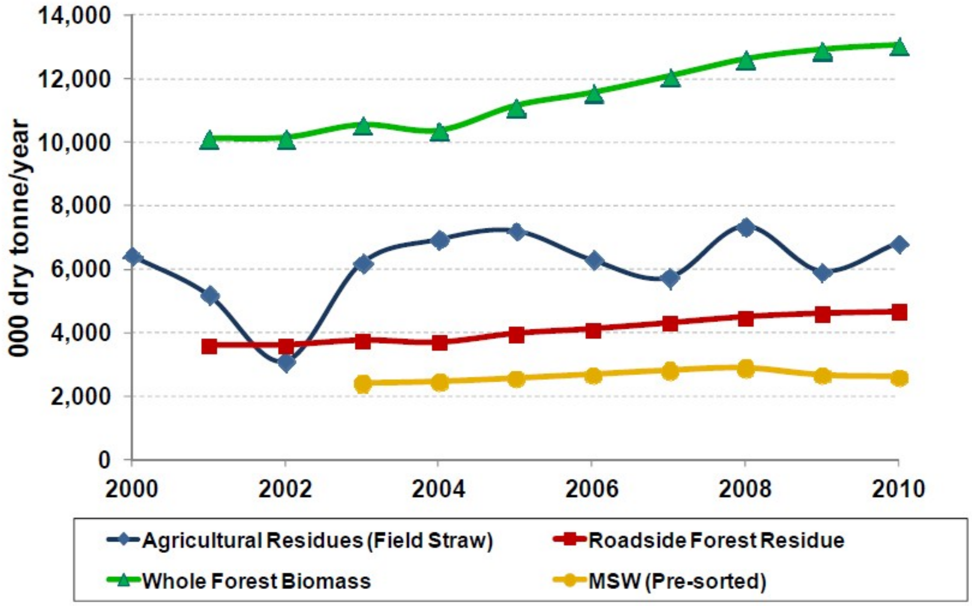

Figure 2.1: Available Biomass and MSW Resources in Alberta [5]

In terms of biofuel consumption, the 2012 provincial biofuel consumption was 413 million liters of bioethanol and 143 million liters of biodiesel, more than 90% of which were imported [5]. The 2012 annual production of of biofuel was reported to be 40 million liters of ethanol and 19 million liters of biodiesel. Capacity for combined heat and power generation using biofuel is 300MW and the electricity generation capacity from gasification and cofiring of biomass is 17 MW and 60 MW, respectively [25].

As of October 2014, there are several plants in Alberta which produce different types of bioenergy. There are two operating plants (producing 78 million liters of bioethanol), two plants being commissioned (expected to produce 265 million liters of biodiesel and 38 million liters of ethanol) and two plants producing 120,000 tonnes of wood pellets per year [5]. There are several other projects that are expected to become operational in short to mid-term as summarized in Table 2.1.

Table 2.1: Short to Mid-Term Bioenergy Projects in Alberta [25]

Ethanol production	76 ML in two facilities
Biodiesel Production	66 ML per year
Electricity from Gasification	75 MW in two facilities
Electricity from Biogas	2 power plants
Pyrolysis Products	5 plants
Biomass to Liquid Products	17 Plants
Combined Heat and Power	10 Plants
Synthesis Natural Gas Production	2 plants

2.2 Bioenergy Potential

The historical provincial maximum biofuel production potential (by fuel type) is summarized in Table 2.2. There are also long-term plans to expand the bioelectricity generation capacity in the province. In total, bioelectricity generation capacity in the province is expected to increase from 516 MW in 2013 [26] to 864 MW in 2034 [5].

Table 2.2: Maximum biofuel potential in Alberta [5]

	Average production 2000-2010 ('000T)	Maximum Ethanol Production ($^9L/Y$)
Wheat	6946	3.79
Barley	5000	2.05
Oats	668	0.27
Total		6.1
	Average production 2000-2010 ('000T)	Maximum Biogas Production ($^6m3/Y$)
Cattle Manure	27.36	875.5
Pig Manure	2.24	82.88
Total		958.4
	Average production 2000-2010 ('000T)	Maximum Biodiesel Production ($^9L/Y$)
Canola	2997	1.19

Considering forest and agricultural biomass, James (2009), investigated the ultimate bioenergy production potential from cellulosic biomass in Alberta. In estimating the potential, no geographical constraints are taken into consideration (i.e. economic constraints imposed by the cost of transportation, cultivation etc.). The results suggest the maximum yearly availability of 7 million bone-dry tonnes of forest biomass and 15 million bone-dry tonnes of agricultural biomass (straw or crop residue)(380 to 420 Petajoule) which is equivalent to 10- 15% of the current total energy demand in the province [6]. In estimating the potential, factors such as impacts of improvements in the crop yield on availability of straw and also the maximum amount of straw that can be used for bioenergy production without adversely affecting the carbon balance of the land are considered [6].

Despite the considerable potential for production and utilization of bioenergy in Alberta, the production of bioenergy is relatively small compared to other jurisdictions in the world [27]. There are some barriers which hinder the penetration of bioenergy technologies within the energy system of the province. Kumar et al., (2003), argued that bioenergy is more expensive than fossil fuel and governmental support is needed for promoting bioenergy [24, 28]. Another consideration is supply variability due to yearly fluctuations in bio resource yields which can impact the security of the supply [3]. In addition, physical capacity of the ecosystem including the amount of biomass, its distribution and its potential uses as a source of energy are expected to impose some geographical restriction and, therefore, adversely affect the economic feasibility of bioenergy sources [6].

2.3 Bioenergy Supporting Policies

Alongside federal policies [27], the Alberta Government has also developed and implemented different supporting policies to promote bioenergy in the province in the past several years. Within the Alberta Nine-Point Bioenergy Plan (ANBP), different regulatory and support policy schemes are developed offering a total of $239 million for different bioenergy projects, details of which are provided in Appendix A, Table A.1 [5, 29]. ANBP supports bioenergy projects through different schemes including commercialization/market development program (CMDP), bioenergy infrastructure development grant program (BIDGP), renewable energy producer credit program (REPCP), energy micro-generation standards and policy revisions (MSPR), bio-industrial network development (BIND), taxation and investment instrument for the bioenergy sector (TIIBS), national renewable fuel standard and energy market targets (BRFS and MT), specified risk material (SRM) disposal protocol (SRMDP) and investment support through existing programs that align with bioenergy development (ISBP) [30].

Chapter 3

Penetration of Bioenergy in the Energy System

We have classified the drivers of the bioenergy development into two categories, namely primary and secondary drivers. The primary drivers of bioenergy in the energy system are those related to existing natural capacity, environmental concerns and issues regarding security of supply. More precisely, we can consider the availability of the natural resources as the primary factor that promotes the adoption of bioenergy. However, the existence of natural resources does not necessarily result in technology development and large scaled utilization of these resources. So, there is a need for technology-push and market-pull measures that facilitates the penetration of bioenergy resources in the market. We have categorized these group of drivers as the secondary drivers of bio-fuel which are imposed by the governments in the forms of regulations and policy measures aiming at promoting bioenergy (generally known as bioenergy supporting policies). The secondary drivers are usually designed to address and intensify the primary sets of drivers.

Drivers of bioenergy adoption change with time [15-17] and therefore their impacts will be realized during time. Both primary and secondary drivers can be the result of global or national/local concerns and regulations. For example, climate change as a global issue and water pollution as a local issue are both categorized as environmental concerns (primary drivers). Similarly, standards and regulations (secondary drivers) could be large scale such as the resulting regulations from implementing EUETS and EU 202020 schemes or small scale such as renewable portfolio standards in different states within US.

In the next section the primary drivers which affect the promotion of the bioenergy in the system, will be discussed in more details.

3.1 Primary Drivers

3.1.1 Resource Availability

In general, availability of existing local bio-resources (bioenergy potential (BEP)) is a very important factor which impacts the implementation rate of renewable energy projects [31]. In Nordic countries, for example, bioenergy has traditionally played an important role as a source of energy [14, 16]. Concerns about foreseen shortage of fibers was one of the reasons for further developing bio-resources in Sweden and resulted in increase in the availability of bio-resources for energy production [16]. From the supply side perspective, forest owners and forest industries are key players in the bioenergy system who can impact the availability of resources [15].

3.1.2 Environmental Concerns

Environmental concerns can restrict the use of some low-carbon options such as nuclear energy and hydro power and, therefore, increases the competitiveness of other renewable sources [16]. Although concerns about climate change are categorized as a non-effective driver [14], global warming underlines the importance of bioenergy as a carbon neutral energy [16]. If these concerns are accompanied with suitable policy measures (e.g. Carbon Tax) the results on promoting bioenergy can be substantial [15]. Public acceptance is also one of the other drivers for promoting bioenergy in the system [16] which is closely related with environmental concerns.

3.1.3 Economic Development

The effect of alternative sources of energy on the job creation is also an important factor [31, 32]. Therefore, to align with their economic development programs, governments might design supportive measures for alternative energy sources which could result in job creation and therefore help the economic development in the country.

3.1.4 Energy Cost and Security

Local cost of energy is a determining factor affecting on the economic competency of renewable energy technologies [31]. Having access to alternative sources of energy can mitigate the vulnerability of oil importing countries and increase their security of supply [16, 33].

3.1.5 Structure of the Energy System

Structure of the existing energy sector is an important factor which could affect the penetration rate of alternative sources of energy both negatively and positively. Factors such as technological difficulties for integrating alternative sources of energy into the fossil fuel based system as well as economic and political restrictions arising from technological lock-in will decelerate the penetration of renewable technologies within the energy system. On the other hand, if some types of renewable technologies are already integrated into the current energy system, consumers may be willing to adopt more technologies of that kind. Besides, if policies supporting renewable technologies exist, it may be easier for policy makers to expand those policies to support newer technologies or to support further expansion of existing technologies.

3.1.6 Energy Consumption

Industrial growth results in economic growth but with growth, the energy consumption of industry also increases. Economic growth can also change consumer behavior such that more energy is consumed. Overall, increased net energy consumption means more resources are required to meet the increasing demand for energy. The increased demand for resources can motivate the need for renewable energy; thus, energy consumption is an important factor affecting the choice of energy. An increase in renewable energy share can result in reduction of overall energy cost from renewable technologies thus making them economically feasible [16]

3.2 Quantifying the Primary Drivers

Indexes are needed to quantitatively assess the impacts of primary drivers in facilitating the penetration of bioenergy. Quantitative measures are assigned to the primary drivers and are selected in a way so that they account for the diversity of the economy and geographical differences between jurisdictions. Comprehensive analysis has been done in order to address limitations for indexing the parameters as discussed below. The assumptions are described in detail in sections 3.2.1 to 3.2.6.

3.2.1 Resource Availability Index

As mentioned in Chapter 1, there exist different sources for bioenergy production including municipal waste, agricultural residues and forestry products. Historical trends in bioenergy production in different countries shows that solid biofuels (dominated by forestry products) are the main source of bioenergy production [34]. Therefore, availability of forestry products is considered as an indicator of availability of bioenergy resources [14]. The availability of forest products is directly related to forest area. Therefore, the area of forests available in the jurisdiction of interest is considered as the index for availability of bioenergy resources.

3.2.2 Environmental Concerns Index

There are several environmental impacts associated with production and consumption of energy including the impacts on water resources and air quality. However, in recent years there has been considerable attention to climate change and greenhouse gas emissions. For example, as of June 2013, 192 parties joined the Kyoto protocol including those with binding targets for GHGs emissions mitigation targets and those without binding targets. Considering the global concerns about climate change, and also its considerable impacts on promoting alternative sources of energy, GHGs emissions is considered as a quantitative indicator of environmental impacts. In order to account for the size and structure of an economy (i.e. energy intensive economies and less energy intensive economies) the ratio of carbon dioxide emissions from energy sector to the total national GHGs emissions from all sectors in the country is selected as the indicator.

3.2.3 Economic Development Index

Gross Domestic Product (GDP) is "an aggregate measure of production equal to the sum of the gross values added of all resident institutional units engaged in production (plus any taxes, and minus any subsidies, on products not included in the value of their outputs)" [35]. GDP is a commonly used index to assess the economic prosperity of a country.

3.2.4 Energy Costs Index

Cost of energy is one of the main factors affecting consumers choice of energy. Consumer energy expenditure is commonly measured by the Consumer Price Index (CPI) of energy. The index is basically a measure of changes in the price level of consumers expenditure on different sources of energy. In order to account for the differences between the size of economies and annual income in the country of interest, the ratio of CPI for energy to the overall CPI is considered as the index for energy cost.

3.2.5 Structure of Energy System Index

Renewable energy index is used to assess the structure of the energy system and analyze the status of renewable energy sources in the current system. The renewable energy index is defined as the ratio of renewable energy production capacity to the total energy production capacity. Applying this ratio instead of absolute renewable energy production capacity allows accounting for the size of the energy system.

3.2.6 Energy Consumption Index

Energy consumption index is the amount of energy consumed per capita which is an important factor to consider both energy consumption to the size of the society at same time. Using energy consumption per capita instead of absolute energy consumption allows an easy comparison between various jurisdictions and its impact on driving share of energy production from various sources. In summary, the primary factors affecting the penetration of bioenergy in the system and the indexes used to quantify them are summarized in Table 3.1.

Table 3.1: Factors Indexes and Abbrevations

Primary Factor	Quantifying Index	Abbreviation
Resource Availability	Forestry area as percentage of land area	BEP
Environmental Concerns	$\frac{Co_2 EmissionsfromEnergySector}{Co_2 EmissionsfromAllSectors}$	EC
Economic Development	Gross Domestic Product	GDP
Energy Price	$\frac{CPIEnergy}{TotalCPI}$	EP
Structure of Energy System	$\frac{RenewableEnergyProductionCapacity}{TotalEnergyProductionCapacity}$	RE
Energy Consumption	Per capita energy consumption	EPC

In Chapter 4, we will investigate the impacts of the primary factors on the bioenergy production capacity using time series analysis.

Chapter 4

Methodology

In chapter 3, the primary drivers of bioenergy in the energy system and their corresponding quantifying indexes have been discussed. This chapter presents the statistical modelling of the primary drivers and analysis of the results for bioenergy promotion.

4.1 Time Series Analysis

Time series analysis is used to assess the impacts of the primary factors on penetration of bioenergy in an energy system. Time series data is comprised of observations of a variable measured on regular time intervals. This time series can be used to forecast the values in the future when time series analysis is performed to identify the relationship of one variable to another variable [36]. A dependent variable is selected which is the target value to be forecasted. A number of independent factors, directly or indirectly related to the dependent variable, are used to define a relationship which can predict the future values of desired variable based on values of all of the independent variables. Time series analysis involves a number of statistical tools to exclude the seasonal or short term variations to approach an accurate model [37].

In the current study, time series analysis is used to identify the impacts of primary factors on bioenergy production capacity relative to total primary energy demand.

$$\frac{bioenergy}{totalprimaryenergy} \equiv BPT = f(BEP, EC, GDP, EP, RE, EPC) \quad (4.1)$$

In equation 4.1 BPT stands for the ratio of the bioenergy over the total primary energy. BEP, EC, GDP, EP, RE and EPC represent the availability of resources (bioenergy potential), environmental concerns, GDP, energy price, share of renewable energies in the energy system and the per capita energy consumption.

In order to reflect the Province of Alberta in Canada, data from the Organization of Economic Co-operation and Development (OECD) are used for the time series analysis. OECD members are the worlds most prosperous economies and also emerging economies with the biggest share in the global economic development and energy consumption [38]. Canada, as a developed country, is a member of the OECD. Therefore, it is assumed that the bioenergy development trends in both Canada and other OECD countries would be similar (to an acceptable degree). In other words it is assumed that the main drivers of bioenergy development are different for industrial and developing countries. So, only the data from the industrialized countries is considered for this analysis. Therefore, OECD countries (with almost similar economic development status to that of Alberta) are considered. Due to the fact that bioenergy production is more mature in European countries, especially countries such as Sweden and Finland that have been pioneering countries in terms of bioenergy production, the historical time series analysis have been focused on OECD Europe. This makes it possible to learn from the experience of these countries and apply results to Alberta.

4.2 Data

For Alberta, the historical data for all the primary factors and also the objective function was collected from publicly available data bases including the International Energy Agency (IEA) World Energy Statistics and Balances [39], OECD library World

Energy Statistics [34], Food and Agriculture Organization of the United Nation (FAO) forestry database [40] and United Nation Economic Commission for Europe (UNECE) Forestry Department [41].

The original data was processed in Microsoft Excel to generate data which could be used in modelling. In other words, the raw data was used to produce the indexes as discussed in Section 3.2. The time period for which the data were reported in different databases was various. Therefore, for the purpose of consistency, a common time period between different studies were selected which was long enough for conducting a meaningful time series analysis (i.e. time period between 2002 and 2011). The comprehensive set of data are provided in Appendix B.

4.3 Modelling

EViews software has been used for data analysis [57]. EViews is a standard statistical computer program suited for regression analysis with time-series data. EViews is one of the most popular econometric packages which provide tools for data analysis, regression, and forecasting. It contains a host of updated econometric features [42] and offers a variety of sophisticated regression and forecasting tools [43].

4.4 Model Development

The initial sets of OECD data are used to develop the regression model presented in Equation 4.2.

$$\begin{aligned} \ln(BPT) = C(1) + C(2)\ln(BEP) + C(3)\ln(EP) \\ +C(4)\ln(GDP) + C(5)\ln(EC) + C(6)\ln(EPC) + C(7)\ln(RE) \end{aligned} \tag{4.2}$$

where C is the array of coefficients for the quantifying indexes. The goal is to fit the OECD data into Equation 4.2 and estimate the corresponding coefficients.

Table 4.1: Eviews regression output report for the first model (considering all parameters)

$\ln(BPT) = C(1) + C(2) * \ln(BEP) + C(3) * \ln(EP)$ $+C(4) * \ln(GDP) + C(5) * \ln(EC) + C(6) * \ln(EPC) + C(7) * \ln(RE)$				
	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	-62.30128	22.96046	-2.713416	0.0730
C(2)	16.78081	2.921006	5.744872	0.0105
C(3)	-0.235241	0.174202	-1.350395	0.2697
C(4)	-0.245571	0.240369	-1.021643	0.3821
C(5)	-0.156038	1.527899	-0.102126	0.9251
C(6)	0.087618	0.703505	0.124545	0.9088
C(7)	0.405211	0.306413	1.322435	0.2778
R-squared		0.998004	Mean dependent var	-3.061401
Adjusted R-squared		0.994012	S.D. dependent var	0.180210
S.E. of regression		0.013945	Akaike info criterion	-5.511418
Sum squared resid		0.000583	Schwarz criterion	-5.299609
Log likelihood		34.55709	F-statistic	250.0170
D urbin-Watson stat		2.592817	Prob(F-statistic)	0.000389

Results of the statistical analysis are summarized in Table 4.1 which can be divided into three sections. The detailed information of various characteristics are provided below:

- The top portion of the table summarizes the input model for regression.
- The middle portion of the table gives statistical information about each regression coefficient.
- Summary statistics about the whole regression equation are presented in the bottom portion of table.
- In middle portion of the table, the names of coefficients appear in the first column and estimated values are shown in the columns to the right.
- The third column in the middle portion of the table gives the standard error associated with each regression coefficient that gives a measure of uncertainty about the true value of the related regression coefficient.

More detailed analysis of the results is done by evaluating the model outcome against various statistical indexes with which the credibility of the regression can be assessed. The following indexes are used to evaluate the accuracy of the modelling:

- "R^2" measures the overall fit of the regression line, in the sense of measuring how close the points are to the estimated regression line. EViews compute R^2 as the fraction of the variance of the the dependent variable explained by the regression (independent variables). $R^2 = 1$ means the regression fit the data perfectly and so the more it is close to 1, the more exact the model is.

- "sum of squared residuals", "log likelihood", "Akaike info criterion", and "Schwarz criterion" are used for making statistical comparison between two different regression. It means that they do not really help about the regression that we have developed.

- "Mean dependent var" and "S.D. dependent var" report the sample mean and standard deviation of the variables.

- "Adjusted R-squared" makes an adjustment to R^2 to take into account the number of the variables in the regression. R^2 measures what fraction of the variation in independent variable is explained by the regression. When another independent variable is added to a regression, R^2 always increases (this is a numerical properties of least square). Adjusted R^2 subtracts a small penalty for each additional variable added.

- "T-statistic" and "probability (prob.)" are different ways of looking at the same issue. The t-statistic, which is computed as the ratio of an estimated coefficient to its standard error, is used to test the hypothesis that a coefficient is equal to zero. To interpret the t-statistic, you should examine the probability of observing the t-statistic given that the coefficient is equal to zero. This probability is also known as the p-value or the marginal significance level. Given a p-value, you can tell at a glance if you reject or accept the hypothesis that the true coefficient is zero against a two-sided alternative that it differs from zero. For example, if you are performing the test at the 5% significance level, a p-value lower than 0.05 is taken as evidence to reject the null hypothesis of a zero coefficient. The p-values for t-statistics are computed from a t-distribution.

- "F-statistic" and "Prob(F-statistic)" come as a pair and are used to test the hypothesis that none of the explanatory variables actually explain anything. "F-statistic" computes the standard F-test of the joint hypothesis that all the coefficients except c(1) are equal zero. "Prob (F-statistic)" displays the Probability Value corresponding to the "F-statistic". In the current, it is not possible for coefficients of the right hand side variable to be equal to zero.

- "Durbin-Watson" is the classic test statistic for serial correlation. A Durbin-Watson close to 2 is consistent with no serial correlation, while a number closer to 0 means there is probably a serial correlation.

It is clear from Table 4.1 that the p-value (Prob.) of EC, GDP and EPC are high. In other words based on the statistical tests, the results suggest that the importance of these factors on the objective function (share of bioenergy in the system) is negligible and therefore these factors can be eliminated from the model. Therefore, in the next stage, the above mentioned variables are eliminated and the model is developed based on the remaining factors.

Detailed results for the second stage of modelling are shown in Table 4.2. As shown in the Table 4.2, the accuracy of regression is promising. The R-squared and Adjusted R-squared are almost 0.997 (in the best case they can be 1) and the Prob. (F-statistic) is zero. The overall results lead to equation 4.3 which shows the impacts of different drivers on promoting the application of bioenergy within the energy sector.

$$\ln(BPT) = -59.62 + 15.96\ln(BEP) - 0.34\ln(EP) + 0.46\ln(RE) \tag{4.3}$$

The equation suggests that the most important factor affecting the penetration

Table 4.2: Eviews regression output report for the second Model (Including selective parameters)

$\ln(BPT) = C(1) + C(2) * \ln(BEP) + C(3) * \ln(EP) + C(7) * \ln(RE)$				
	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	-59.61708	6.540007	-9.115751	0.0001
C(2)	15.95513	1.964197	8.122977	0.0002
C(3)	-0.335184	0.125250	-2.676119	0.0367
C(7)	0.461205	0.128340	3.593620	0.0115
R-squared		0.997682	Mean dependent var	-3.061401
Adjusted R-squared		0.996522	S.D. dependent var	0.180210
S.E. of regression		0.010627	Akaike info criterion	-5.961636
Sum squared resid		0.000678	Schwarz criterion	-5.840602
Log likelihood		33.80818	F-statistic	860.6758
D urbin-Watson stat		2.698407	Prob(F-statistic)	0.000000

rate of bioenergy technologies in the energy sector is the availability of resources for bioenergy feed stock (BEP) followed by availability of infrastructure for implementing renewable energy technologies (share of renewable in net energy production), (RE), and the cost of energy, (EP). While availability of resources and appropriate infrastructure has a positive relationship with the share of bioenergy in the energy system (i.e. increase in this factors will help promoting bioenergy), the energy price is found to have negative impacts on the objective factors. The results suggest that increasing share of energy expenditure in the overall household/industry expenditure will motivate consumers to use less expensive energies which is conventional fossil fuel energies and thus decrease the demand for renewable energies including bioenergy.

Figure 4.1 shows the results of the second stage of modeling in which availability of resources, price of energy and structure of the energy sector are considered to be the factors which determines the share of bioenergy within the system.

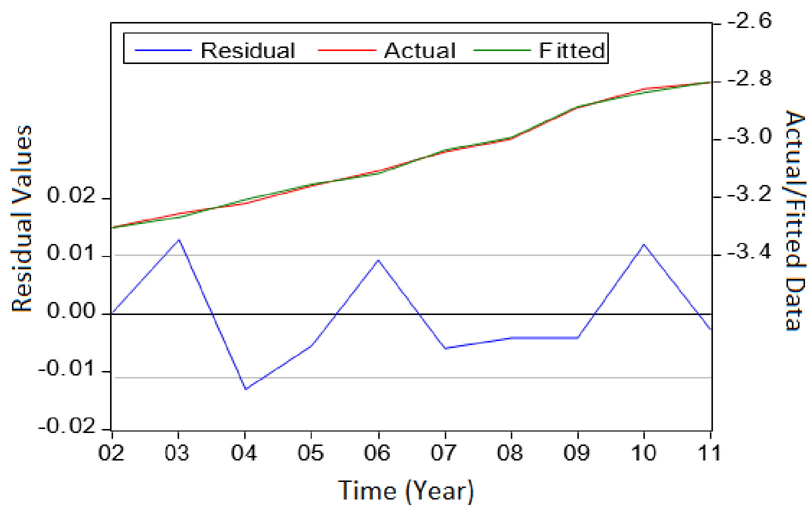

Figure 4.1: Regression Model Considering the Most Important Influencing Factors Actual, Fitted, Residual Graphs

In Figure 4.1, the residual values are plotted against the left vertical axis and the actual and fitted data are plotted against the right vertical axis. The horizontal axis shows the time. As shown in the figure, actual and fitted data are completely covering each other in each year and the residual values are fluctuating around zero which underlines the accuracy of the model. Moreover, there are no outliers (points with big positive or negative values) in the model.

Chapter 5

Results and Discussion

The modeling results clearly indicate that out of all factors considered for driving bioenergy share in a society three factors play a major role: bioenergy potential (BEP), relative energy costs (EP) and share of renewable energy (RE).

The first factor (BEP) is the bioenergy potential which indicates the availability of feed stock for bioenergy production. The feedstock availability plays a key role in deciding plant size and energy price so the limited feedstock availability has considerable impact on bioenergy potential [44].

The second factor (EP) is relative energy costs for a consumer to their net expenditures. Higher energy cost leads towards the use of cheaper fossil fuels and hinders bioenergy expansion [14]. Thus, energy cost is a localized economic factor that plays a vital role in defining future of energy policies. Lower energy costs allow production of bioenergy without any incurring extraordinary energy costs on the consumers.

The third important factor highlighted by model (RE) is the share of renewable energy in net energy production. Increasing share of renewable energy increases the share of bioenergy in the system. This is because the more the share of renewable energy in the system is the more familiar both consumers and policy makers are with the advantages of these energy sources and therefore they are willing to adopt more alternative energies including bioenergy.

5.1 Verification of the Results

Experience of pioneering countries in promoting renewable energies in general and bioenergy in particular shows that there is no silver bullet policy that facilitates the penetration of alternative energies within the energy sector and a combination of policies are needed for this purpose [45]. Generally, conventional policies for promoting alternative energies can be classified in two different categories: supply-push strategies which try to push technologies into the market through direct subsidies and demand-pull mechanisms that primarily focus on the market to create demand and pull the technologies into the energy system [46]. Figure 5.1 shows the classification of various incentives according to the above definition [47].

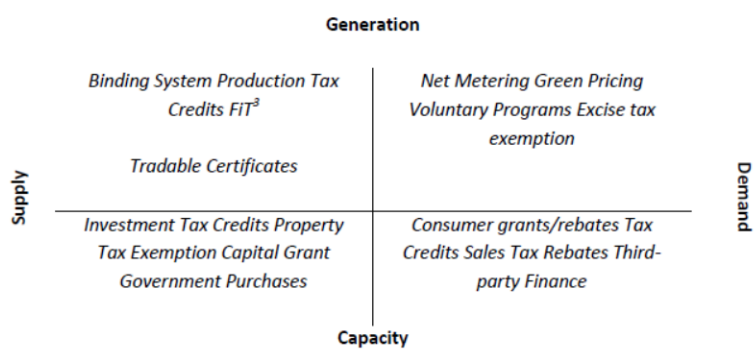

Figure 5.1: Renewable energy technologies promotion policies [47]

In their study, Brer and Wstenhagen (2009) have surveyed 60 investment professionals from European and North American venture capital and private equity funds and ask their opinion about effectiveness of various policy measures in stimulating their interest for investment in renewable energy technologies projects. The results highlights the importance of both demand-pull and supply-push policies [48]. Based on the results of the survey, they scored each policy measure (Figure 5.2 and 5.3). The overal results show that governmental demonstration plans, different financial supporting policies and also performance standards are the most important factors (all with the scores more than 3.5) which affects the investors choice of investment.

This is inline with the findings of the current study where we found relative price of bioenergy and the current status of bioenergy are important factors for further promotion of bioenergy within the system. More preciecely, governmental demonstration plans are expected to help introducing new alternative sources of energy which will then be promoted automatically when consumers and industrial owners realize their advantages. The financial support policies (in this case, feed in tariff, reduction of fossile fuel subsidies and residential and commercial tax credits) will help economic competitivenss of renewable energies which is considered as the energy price index (CPI Energy/Total CPI) in the current study.

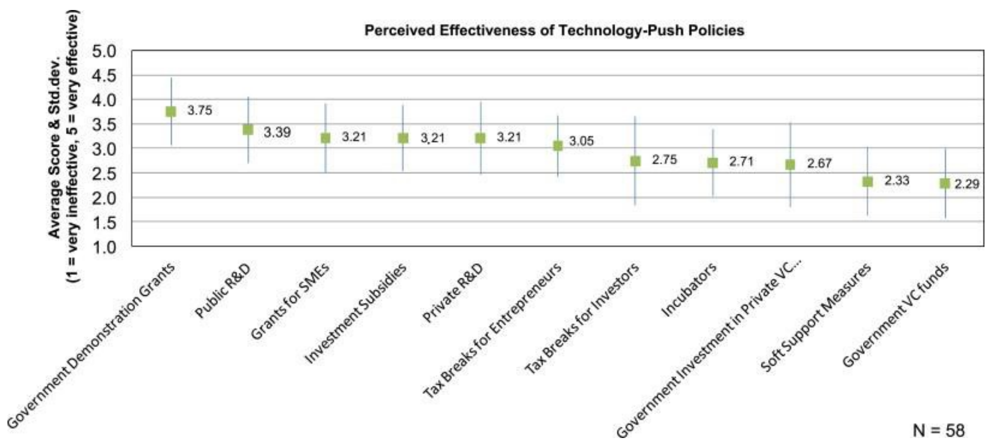

Figure 5.2: Perceived Effectiveness of Technology-Push Policies [48]

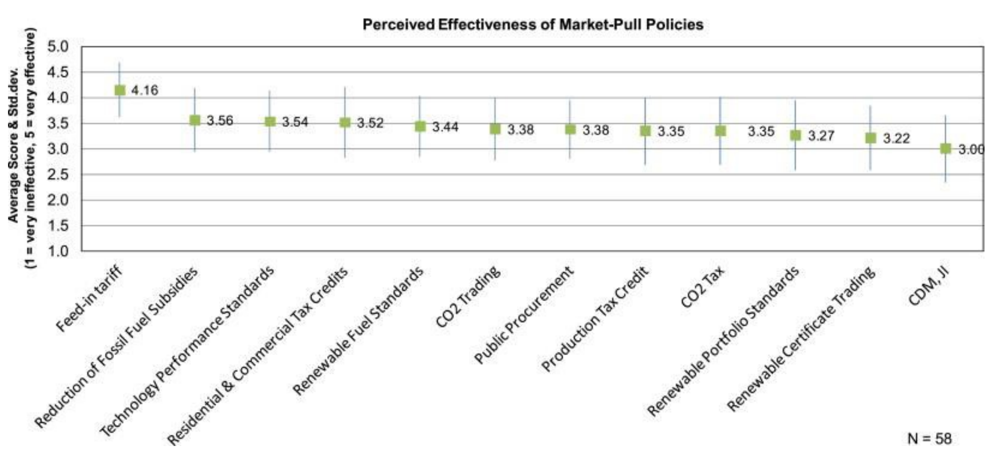

Figure 5.3: Perceived Effectiveness of Market-Pull Policies [48]

Similar to the study by Brer and Wstenhagen (2009) experience of pioneering countries in the area of bioenergy production and utilization shows the higher effectiveness of some policies compared to the others. In Sweden and Finland, as the two countries with the highest share of bioenergy in the system, availability of resources was identified as the main driver of bioenergy within the system [14, 15, 17, 31, 49]. The advantages of using bioenergy were initially recognized by the industries that were already active in the area (e.g. pulp and paper) and then expanded to the larger society. This highlights the importance of both availability of resources and also acceptance of the technologies in the system. Being examined in Sweden and Finland (among other countries), research and innovation polices are found to have minimal impacts in promoting bioenergy technologies in the system [14, 15, 17]. On the other hand market deployment polices are identified to be more effective in promoting bioenergy for which stabilized and continuous policies are prerequisite [14, 31].

Monetary policies which basically aim at increasing the economic competitiveness of bioenergy technologies (through reducing the bioenergy prices or increasing the prices of conventional fossil fuels) are also found to have considerable impacts on expanding the adaptation rate of bioenergy technologies in the system[15] [17] [49]. The financial support policies were implemented in the different forms including subsidizing bioenergy, different taxation schemes in favor of alternative energies, quota system in Sweden and Finland. Among all the policies which have been implemented since 1985, feed in tariff is found to be the most effective financial policy to support bioenergy [15] [17] [49].

Chapter 6

Implication for Alberta

6.1 Bioenergy potential in Alberta

The bioenergy potential can be discussed in terms of feed stock availability and factors involving stable supply of this feed stock (contract with suppliers, collection and transportation). Alberta has high amount of feed stock available that can be utilized for bioenergy production as shown in Table 1.3 [5]. So the remaining obstacle is in terms of supply of this feed stock to the plant location. If the government policies are inconsistent the suppliers are reluctant to enter a long term supply contract [50]. In Alberta, a nine point bioenergy plan was introduced to promote bioenergy but the program was short term and new programs are yet to be announced (Appendix A). This discourages the suppliers for long term commitment due to high risks involved. The forest is owned by a number of companies in Alberta which also creates a hindrance in terms of contracting with all companies individually [5].

Other barriers effecting the availability (and accessibility) of the resources for bioenergy production are technological limits since the feed stock available has varying moisture content which limits plant productivity [44]. Also, the farmers do not have adequate experience in growing energy crops which can significantly contribute as feed stock backup [51]. The natural conditions or disasters have significant impact in on supply of feed stock. Forest fires, extreme weathers can reduce the feed stock production, collection and transportation [44]. In the case of Alberta, extreme weather conditions and the large distance between sources of energy and the demand location are negatively affecting the economic feasibility of the bioenergy production. Overall the feed stock is available in Alberta but market for feed stock supply for bioenergy needs restructuring. Reluctance of suppliers to signing long term agreements (which itself is due to weak government policies) is major barrier for availability of continuous supply of biomass for bioenergy production.

6.2 Energy Price

The energy price factor is based on CPI of energy ratio to the total CPI. The modeling result shows that this factor is inversely related to the bioenergy production share. Higher CPI of energy to total CPI will impact the consumers choice of energy. More precisely, when share of energy expenditures increases in the total household/industry expenditure, they tend to use cheaper energy which basically comes from fossil fuel. In Alberta natural gas and coal are cheap compared to relative cost of bioenergy production which reduces the bioenergy scope in Alberta.

The cost of bioenergy can be brought down by providing a number of incentives from the government sector to account for carbon savings. In Alberta, the nine point bioenergy project introduced a number of such incentives, but as mentioned, these incentives were short term and most of them are in proposal stage. The lack of appropriate governmental policies, high risks associated to feed stock collection and technological limits are also causing issue in terms of collecting finance for bioenergy plant from investors and banks [44, 50, 52]. In some circles, bioenergy is considered a threat to bio-diversification and forest sustainability [5] that discourages the governmental support in terms of incentives for bio energy. All these factors collectively increase the price of bio energy and make them less attractive for consumers and investors due to presence of cheap alternatives.

Overall, the government has to play a major role in controlling the cost of bioenergy by redefining the nine-point bioenergy project and implementing it for long term. The key driving factors, which are usually neglected, for providing such incentives should be that bioenergy plants can significantly reduces carbon emissions as well as create a number of jobs [51, 53].

6.3 Status of Renewable Energy

The renewable energy share plays a vital role in bioenergy production share for a specific jurisdiction. Considering only the electricity sector, Alberta has currently 17% of electricity generation share from renewable energy which is projected to increase by 1% till 2035. But, the electricity share from bioenergy is expected to stay at 3% from 2014 to 2035 [54]. This projection indicates that there are no plans available to increase the bioenergy share regardless of the feed stock availability. There are plans in place to reduce energy production from coal power plants but that is being offset by natural gas instead of considering renewable energy sources (Figure 6.1).

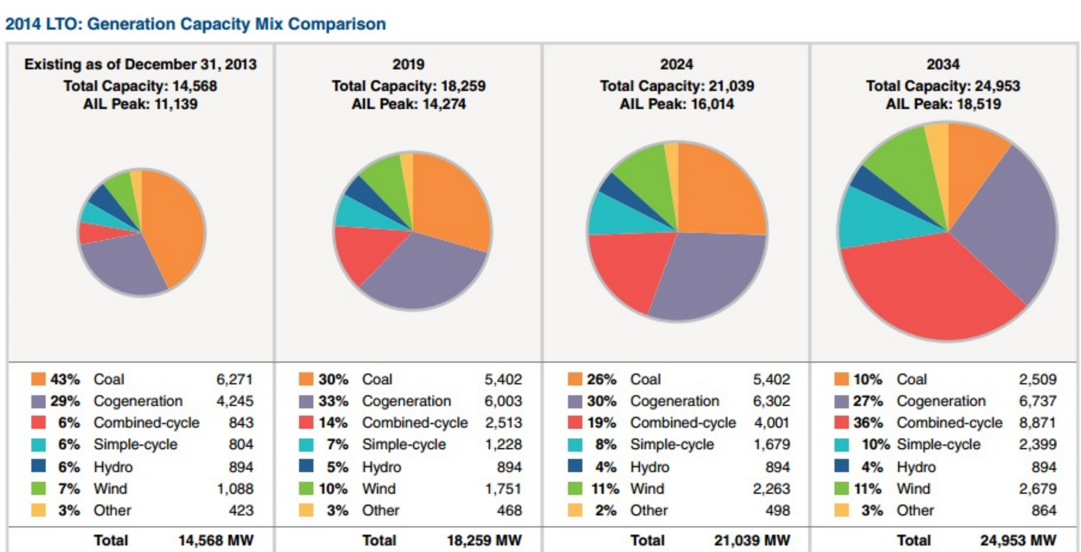

Figure 6.1: Electricity Generation Projections Alberta[56]

The bioenergy expansion for other product paths can also face a number of barriers including lack of proper governmental policies and financial incentives as discussed in section (6.2. Energy price) as well as technical barriers due to varying quality of feed stock [44].

The reduction of carbon emissions must be a priority, and it can be achieved by increasing share of renewable in Alberta. Switching from coal to natural gas is a temporary solution and renewable energy must be used increasingly to mitigate carbon emissions. The regulations from government are prerequisites for a successful selection of a bioenergy plant and expanding bioenergy potential in a division [55].

Chapter 7

Conclusion and Recommendations

7.1 Conclusion

In this project the key factors which affect adoption of bioenergy technologies in the system have been identified and the importance of each factor in promoting bioenergy in the system has been assessed. The applicability of the identified policies for the province of Alberta, Canada, is investigated. By localizing the effective bioenergy supporting policies for Alberta, the deficiencies of current provincial policies have been analyzed. The conclusions are drown as follows:

- We have classified the primary drivers of the bioenergy development into six categories, namely Resource Availability, Environmental Concerns, Economic Development, Energy Cost, Structure of the Energy System and Security and Energy Consumption. The area of forests available in the jurisdiction of interest, the ratio of carbon dioxide emissions from energy sector to the total national GHGs emissions from all sectors, GDP, the ratio of CPI for energy to the overall CPI, the ratio of renewable energy production capacity to the total energy production capacity and the amount of energy consumed per capita have been considered as the quantifying indexes for assessing the impacts of primary drivers in facilitating the penetration of bioenergy.

- Time series analysis is used to identify the impacts of primary factors on bioenergy production capacity relative to total primary energy demand and data from OECD are used to reflect the Province of Alberta in Canada. The results demonstrate that the most important factor affecting the penetration rate of bioenergy technologies in the energy sector is the availability of resources for bioenergy feed stock (BEP) followed by availability of infrastructure for implementing renewable energy technologies (share of renewable in net energy production), (RE), and the cost of energy, (EP).

- Investigating the bioenergy potential in Alberta, it becomes clear that Alberta has high amount of feed stock that can be utilized for bioenrgy production. However there are several barriers affecting the availability of resources for bioenrgy production such as lack of long term bioenrgy plans, technological limits, extreme weather conditions, long distance between sources of energy and demand locations and high cost of bioenrgy production compared to the available cheap natural gas and coal.

7.2 Recommendations

Bioenergy plants can significantly reduces carbon emissions as well as create a number of jobs which can be driving factors for the government to control the cost of bioenergy and redefine a long term bioenergy project for encouraging the suppliers for long term agreements. So, the regulations from government are prerequisites for a successful selection of a bioenergy plant and expanding bienergy potential in a division.

Appendix A

Additional Information

Table A.1: Albertas Nine-Point Bioenergy Plan [30]

Scheme		Framework & Effective Date	Selected desired outcome
Approved	CMDP	$24M(2008-2009)	• Develop/expand/strengthen Albertas biodiesel, biogas and ethanol production capacity in response to market opportunities. • Leverage industry funds to focus on research commercialization, technology transfer, new generation co-operatives, capacity building, market development and advocacy for ensuring market acceptance.

Continued on next page

Table A.1 – *Continued from previous page*

	BIDGP	$6M(2008-2009)	• Leverage industry/investors/municipal funds to develop and expand the distribution infrastructure to connect Alberta produced ethanol, biodiesel and biogas (methane) to the marketplace. • Development and expansion of the distribution infrastructure of biofuel and energy transmission in Alberta.
	REPCP	$209M(2007-2011)	• Encourage production and incorporation of bioenergy products (ethanol, biodiesel, biogas-electrical) within the marketplace.
Proposed	MSPR	-	• Clearly define the regulatory protocols required to establish processing plants like biogas digesters and biodiesel processing facilities. • Through a cross-ministry approach, ensure a timely and transparent review of investment applications better meeting the needs of industry.

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Table A.1 – *Continued from previous page*

	BIND	-	• Facilitate the demonstration and integration of bioenergy processing with existing manufacturing processors for increased regional development. • Demonstrate cluster efficiency - through the strategic integration and clustering of key processors provide a significant improvement in competitiveness and reduced environmental impact.
	TIIBS	-	• Work with Federal counterparts to investigate options to improve capital flow to bioenergy industry.
	BRFS and MT	-	• Align to a five per cent national renewable fuels standard by 2010 to create market stability that will benefit existing renewable fuel industries and establish a future market for newly established fuel technologies.

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Table A.1 – *Continued from previous page*

	SRMDP	-	• Investigate and establish regulatory protocol with the federal government in the safe disposal of SRMs through appropriate bioenergy technology adaptation.
	ISBP	-	• Agriculture Financial Services Corporation (AFSC) lending programs. • New Generation Cooperative Initiatives. • Industry Development Research Funds. • AVAC commercialization funding.

Appendix B

Data

Table B.1: Forest as percentage of Land Area (OECD Europe)

year	BEP
2002	31.5250535945498
2003	31.6348682062575
2004	31.7446828179651
2005	31.8544974296728
2006	31.9643120413805
2007	32.0741266530881
2008	32.1839412647958
2009	32.2937558765034
2010	32.4035704882111
2011	32.5133850999188

Table B.2: CO2 emissions ratio from energy sector to all sectors (OECD Europe)

year	EC
2002	0.757698845
2003	0.763634776
2004	0.767190201
2005	0.766250755
2006	0.77005413
2007	0.769778704
2008	0.774028226
2009	0.767728614
2010	0.769268083
2011	0.767135184

Table B.3: GDP using exchange rates, billion 2005 US dollars (OECD Europe)

year	GDP
2002	13848.026
2003	14050.468
2004	14433.775
2005	14762.792
2006	15263.299
2007	15756.813
2008	15804.502
2009	15148.793
2010	15508.747
2011	15794.89

Table B.4: Ratio of CPI of energy to net CPI (OECD Europe)

year	EP
2002	0.78998779
2003	0.798578199
2004	0.815972222
2005	0.876696833
2006	0.932745314
2007	0.938709677
2008	1.013457557
2009	0.951893552
2010	1
2011	1.078488372

Table B.5: Percentage of renewables to total primary energy production (OECD Europe)

year	RE
2002	12.764
2003	12.328
2004	12.684
2005	13.292
2006	13.396
2007	14.256
2008	14.708
2009	15.784
2010	16.18
2011	16.456

Table B.6: Energy Consumption Per Capita (OECD Europe)

year	EPC
2002	2.5189E+11
2003	2.53339E+11
2004	2.57111E+11
2005	2.5695E+11
2006	2.57437E+11
2007	2.52504E+11
2008	2.52289E+11
2009	2.40021E+11
2010	2.4454E+11
2011	2.38778E+11

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