Czech University of Life Sciences Prague

Faculty of Economics and Management

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Bachelor Thesis

THE ROLE OF BIOENERGY IN THE GERMAN ECONOMY

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BACHELOR THESIS ASSIGNMENT

Le Thi Thu Trang

Economics and Management

Thesis title
The Role of Bioenergy in the German Economy

Objectives of thesis
This thesis attempts to analyse and estimate the effects of bio-energy production and consumption on Germany's economy in a period of 2000-2010.

Methodology
Literature review covers the history of bio-energy in both Europe and Germany as well as the current situation of bio-energy production and consumption in Germany. Analyses were conducted using econometric tools, the most notable of which being Linear Regression Model.

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Declaration

I declare that I have worked on my bachelor thesis titled "The Role of Bioenergy in the German Economy" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the bachelor thesis, I declare that the thesis does not break copyrights of any third person.

In Prague on 17/03/2014 ______________________________

Le Thi Thu Trang

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Role bioenergie v německé ekonomice

The Role of Bioenergy in the German Economy

Summary

As the stress put on the energy security becomes more and more heavy, theres exists an increasing need to find new sources of energy to substitute fossil fuel. While nuclear energy is under heavy criticism because of its health risks, renewable power - for example, wind power, solar energy and bioenergy - have gained their reputation as clean and infinite sources of energy. This thesis attempts to research into the role of bioenergy in Germany's economic production and how its consumption affects Germany's GDP and fossil fuel use.

The first part - literature review - first provides a view on energy as an important factor of production and how a scarcity in energy will lead to a slowed production rate. Next is an overview of bioenergy - its defintion, classification and its appearance in history, followed by a summary of bioenergy's current situation in Europ in general and Germany in particular. The practical part uses regression models to estimate the extent of bioenergy usage's effect on GDP and petroleum use in Germany.

Keywords: bioenergy, Germany, economic analysis

Souhrn

Jako kmen na energetické bezpečnosti se stává těžší a těžší, existuje rostoucí potřebu najít nové zdroje energie k nahrazení fosilních paliv. Zatímco jaderná energie je pod palbu kritiky kvůli jeho zdravotní rizika, obnovitelné zdroje energie - například, větrná energie, sluneční energie a bioenergie - získal svou pověst jako čisté a nekonečné zdroje energie. Tato práce se snaží výzkumu v roli bioenergie v německé hospodářské produkce a vliv jeho spotřeba HDP v Německu a používání fosilních paliv.

První část - přehled literatury - nejprve poskytuje pohled na energii jako důležitý faktor výroby a jak se nedostatek energie povede k míře zpomalení výroby. Dále je zejména přehled bioenergie - definice, klasifikace a jeho vystoupení v historii, následuje přehled současné situace je bioenergie v Evropě obecně a v Německu. Praktická část využívá regresní modely k odhadu míry využití bioenergie vliv na HDP a ropy používaná v Německu.

Klíčová slova: bioenergie, Německo, ekonomická analýza

Table of Content

I. Introduction

Energy has always played a key role in economic production, and as a result, it is also an extremely significant factor in economic growth. However, the role of energy provision in the development of economy used to be downplayed by most economists, as in the past, the abundance of energy sources allowed most economic models to be realized without taking energy issues into account.

Currently, fossil fuel is the primary source of energy: In 2007, it was estimated by The Energy Information Administration that the primary sources of energy consisted of petroleum 36.0%, coal 27.4%, and natural gas 23.0%, amounting to an 86.4% share for fossil fuels in primary energy consumption in the world.[1] However, the resources of fossil fuel are being depleted at a high speed, and as a non-renewable source of energy, fossil fuel cannot be sustained - it is facing the risk of being completely depleted and putting economic production under the strains of energy scarcity. In order to lessen the adverse effects of fossil fuel scarcity on the economy, along with several other reasons, alternate sources of energy have been sought after and utilized, the two most notable of which being nuclear energy and renewable energy. While nuclear energy production is facing criticism for potential environmental and human health harm, several sources of renewable energy have been successfully applied, and among these resources, bioenergy is quickly recognized as the most abundant and versatile sources of renewable energy which has potential to compete with fossil fuel, whose price has been rising incessantly and, along with its scarcity, threatening the world energy security.

[1] Data retrieved from http://www.eia.gov/: *The U.S. Energy Information Administration (EIA)*

With the application of bioenergy in economy, the burden of energy provision appears to have been put off the shoulder of fossil fuel. However, as bioenergy has yet to be able to fully replace fossil fuel as the main energy source for economic production, along with the fact that certain types of machinery are not compatible with bioenergy, governments have to provide subsidies for bioenergy in order to increase its competitive power with fossil fuel. The question is, with its current state, does bioenergy play any role in economic development?

II. Objectives, Methodology and Hypothesis

2.1. Objectives

The main objective of this thesis is to evaluate the impact of bioenergy consumption on Germany's economic production. The relationship between fossil fuel-based energy consumption and economic production will be inspected, followed by an analysis on the connection between bioenergy consumption and fossil fuel consumption. As biodiesel is the most commonly used bioenergy product in Germany, its consumption will be used to compare with the consumption of petroleum products, which also accounts for the highest percentage of Germany's fossil fuel consumption.

2.2. Methodology

In order to understand the effects of bioenergy consumption on the economy, it is necessary to review on its origin and development. Definitions and main concepts of bioenergy are taken from Wikipedia. An overview on the current policy of both the European Union and Germany regarding bioenergy use is also included. Statistical analyses are conducted based on the hypothesis - data are mainly taken from the European Union's statistics center. The main econometric tool used in this thesis is the Linear Regression Model, which is used to determine the correlation between different sets of data. Trend analysis is also used for predicting future consumption of biodiesel and comparing the prognostic results with the actual data. Microsoft Excel and GRETL are the programs used for estimating the regression model and trend prediction.

2.3. Hypothesis

"Bioenergy consumption significantly affects Germany's economic produtĩon - an increase in bioenergy consumption will help increasing Germany's GDP per capita."

III. Literature review

3.1. One look at energy as a factor of production

As dictated by laws of physics, all activities are bound by energy circulation, and economic production and growth are not an exception. In fact, the crucial role of energy in economic production and growth can be confirmed via the laws of thermodynamics:

- The first law of thermodynamics shows that as a result of energy conservation, the internal energy of a system will change, as heat - the flow of thermal energy from one subject to another - will be transfer either in or out of the system. In terms of economic production, this implies the mass-balance principle: In order to reach the desired number of material output, greater amount of material input must be used as it is certain that there will be residuals and/or waste product[2]. This means that a minimal input requirement for any process must be issued.

- The second law of thermodynamics - the efficiency law - implies that in order to transform a form of matter into another, a minimum amount of energy will be required to perform the transformation[3]. Economic production always involved transforming matters in one way or another, thus there must always be limitations of other factors of production for energy to contribute to the process. All economic processes must, therefore, require energy, so that energy is always an essential factor of production[4].

However, energy is not always regarded as a primary factor of production - mainstream economist tend to give the role to capital, labor and land as three primary factors of

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[2] Ayres, R.U., and A.V. Kneese 1969 Production, consumption, and externalities. *American Economic Review* LIX(3): 282-297

[3] Baumgärtner, S. (2004) Thermodynamic Models, In: J. Proops and P. Safonov (eds), Modelling in Ecological Economics, Cheltenham: Edward Elgar, 102–129.

[4] Stern, D. I. (1997). “Limits to substitution and irreversibility in production and consumption: a neoclassical interpretation of ecological economics.” Ecological Economics, 21: 197-215.

production, while energy sources and materials tend to be put into the category of intermediate inputs. As most of the standard macroeconomic theories also focus on these three primary factors, especially labor and capital, the role of energy as a driver in economic production and growth is eventually downplayed. It was not until energy sources became scarce that its role was reconsidered, thus creating a future viewpoint which shows that scarcity of energy will greatly constraint economic development.

3.2. Bioenergy: A potential replacement of fossil fuel

As shown in the previous section, energy scarcity proves to be a threat to economic production and growth. To counter this issue, numerous possible solutions have been applied in the production model - from adapting production models that are more energy-efficient to seeking for alternative sources of energy that can be renewed in a reasonable amount of time (unlike fossil fuel). Among the current utilizedsources of renewable power, bioenergy (also known as biofuel) is gaining its reputation as the source of energy that has the potential to completely replace oil as an energy source for transportation and other oil-required machineries.

3.2.1. Definition and classification

According to Wikipedia:

> *"**Bioenergy** is renewable energy made available from materials derived from biological sources. Biomass is any organic material which has stored sunlight in the form of chemical energy. As a fuel it may include wood, wood waste, straw, manure, sugarcane, and many other byproducts from a variety of agricultural processes."*

Biomass may include:

- animal wastes
- agricultural feed crops, waste and residues
- aquatic plants
- landfill gases
- municipal wastes

- trees, wood waste and residues
- other organic waste materials.

In short, bioenergy can be used to refer to every type of energy that is produced from biomass - but in its narrower sense, bioenergy tends to be used as a synonym of "biofuel", which is used to describe fuel that is derived from biological sources. This thesis will discuss the use of bioenergy in Europe mainly in the form of liquid fuel.

Currently, there are two main types of processed bioenergy:

- First-generation bioenergy is made from crops, such as starch, sugar or extracted oil from vegetables. It is considered a clean and relatively convenient source of renewable energy in Europe. Main products include bioethanol, biodiesel, biogas and other solid biofuel. While bioethanol is the most common source of bioenergy all over the world (especially in Brazil), biodiesel is favored in Europe - which has the highest biodiesel consumption rate worldwide.

- The second-generation bioenergy, also known as the advanced bioenergy, differs from the first-generation bioenergy in one point: it can be generated from any type of biomass, unlike first-generation bioenergy, which can only be extracted from crops and its related products. It can help eliminate the economic, environmental and social limitations encountered by first-generation bioenergy; however, as its main ingredients are residual products or lignocellulosic biomass, the production process appears to be more complicated and difficult than that of first-generation bioenergy.

3.2.2. An overview on the history of bioenergy: a case of the United States

Although bioenergy production as a replacement for fossil fuel has only been recently implemented, energy produced from biomass has already been in practice for a period as long as the entire history of human. In fact, biomass energy was our first source of energy - wood were used for fuel and ancient civilizations were built not by energy from oil or coal, but from human power and wood. And depletion of wood was known to lead to civilizations' downfall[5].

Nowadays, a large portion of the world still depends on wood for heating and candles for lighting. According to energy analysts, they are at the bottom rung of the "energy ladder". As both their and their countries' conditions become more developed, they will eventually "climb" up to a more "advanced" type of fuel, e.g. LP gas and kerosene. The idea of energy ladder is shown in the 2005 Encyclopedia of Energy:

> *Traditional fuels, such as firewood and dung, are relatively inconvenient to collect and store, require constant management while in use, and emit large quantities of smoke that has a detrimental impact on the health of the users. Modern fuels, such as natural gas and electricity are more convenient, cleaner to use, have power outputs that are easily controlled, and can be delivered directly to the kitchen (once the basic transmission and distribution infrastructure is built). The energy ladder or energy transition embodies the idea that as household income rises through the development process, they choose to utilize modern fuels and choose not to utilize the traditional fuels. (Cleveland, 2005)*

But even the most "advanced" source of energy is not finite. Fossil fuel is not renewable in itself, and humanity once again found their alternate sources of energy in the forest. Only this time, it is more refined. The term "bioenergy" no longer keep its broad meaning - to most of people, it is used to describe liquid biofuel - namely bioethanol and biodiesel, along with second-generation cellulosic biofuels systems for internal combustion engines.

[5] Oosthoek, K: *The Role of Wood in World History*. Available at http://www.eh-resources.org/wood.html

Throughout the history of the world, however, bioenergy as fuel has been more than once referred to as the "fuel of the future" and its potential to create a type of energy that is clean, renewable and domestically available has long been recognized. Alexander Graham Bell made this observation concerning alcohol-based fuel in National Geographic in 1917:

> *"Alcohol makes a beautiful, clean and efficient fuel. Alcohol can be manufactured from corn stalks, and in fact from almost any vegetable matter capable of fermentation…We need never fear the exhaustion of our present fuel supplies so long as we can produce an annual cop of alcohol to any extent desired.[6]"*

But no matter how promising it might be, alcohol as a fuel has always had to face its numerous challenges. Throughout its history, biofuel producers have incessantly clashed against petroleum-based fossil fuels and most of them ended up on the losing side, and as a result, bioenergy needs subsidies and preferential tax treatment to survive in the market. The fossil fuel industry, on the other hand, always emerged victorious thanks to its larger political and economic role.

But when we look further back at the past, we find out that bioenergy has had its own moments. In the 1820s, the dominant fuel for lamps in the United States was a blend of camphene and alcohol, and its sale was ten times as much as the sale of the expensive whale oil. Farmers had their own stills to make lamp oil from crop waste. However, in 1862, perhaps due to the high demand for alcohol lamp oil, a $2 per gallon tax was assessed on alcohol to provide financial support to the Civil War. Consequently, alcohol lamp oil experienced an abrupt decline in demand, while kerosene (also known as coal oil at that time) survived, as it was taxed at only 10 cent per gallon. By 1870, kerosene was selling over 200 million gallons a year while alcohol lamp oil almost plummeted into oblivion.

[6] Nayab, N: *Alexander Graham Bell and Renewable Energy.* Article available at http://www.brighthub.com/environment/renewable-energy/articles/97245.aspx

The alcohol tax was repealed in 1906 by Theodore Roosevelt, saying,

> *"The Standard Oil Company has, largely by unfair or unlawful methods, crushed out home competition…It is highly desirable that an element of competition should be introduced by…putting alcohol…upon the [tax] free list.*[7]*"*

And this is not the only tax fight between the two forces - the trend continued right until the next century.

On another note, liquid bioenergy has left its mark since the earliest automotive days. The first internal combustion engine in the United States was built by Samuel Morey in 1826, who used it to run a small boat on the Connecticut River. The fuel he used for the engine was a mixture of turpentine and alcohol[8].

German inventor Nicolaus August Otto is usually credited as the inventor of the first automobile engine[9]. The four-stroke internal combustion engine he developed in 1876 used alcohol as the fuel - in Europe, alcohol was available in abundance and also untaxed. Rudolph Diesel demonstrated his first engine in 190, which ran on peanut oil. The Ford Model T, which first came out in 1908, was also designed to run on ethanol.

But despite the first inventions of alcohol-based automobiles, gasoline still appear dominant on the market - by 1920, there were 9 million gasoline-powered vehicles operating on the road[10].

In the 1930s, a form of gasoline blends with alcohol was introduced in the United States. Agrol, of Atchison, Kansa**s** (now Midwest Grain Products) was backed by Ford but opposed by the oil companies. At one point there were 2,000 stations across the Midwest, but the company went bankrupt in 1939. During the war, ethanol was

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[7] Roosevelt, Theodore: *Special* Message, 1906. Available at http://www.presidency.ucsb.edu/ws/?pid=69667

[8] Western Newyork Energy: *Ethanol's Past*. Available at http://www.wnyenergy.com/index.php?pr=Ethanols_Past

[9] *Nicolas Otto's biography*. Available at http://inventors.about.com/library/inventors/blotto.htm

[10] The U.S. Energy Information Administration: *History of gasoline.* Available at http://www.eia.gov/energyexplained/index.cfm?page=gasoline_history

primarily used to make 75 percent of all synthetic rubber, which was in high demand. Ethanol was also used as an aviation fuel.

Once again, after the Second World War, the price of gasoline dropped, which made it a far more reasonable choice for fuel than ethanol-based fuel. As a result, ethanol almost stopped existing on the market - it was not until the great oil crisis that happened in the 1970s that interest in alternative sources arose again. Professor Thomas B. Reed of MIT was an outspoken advocate for the development of new fuels, but his research was canceled under pressure from Exxon, a major contributor to the school[11]. Nonetheless, "gasohol," a blend of gasoline and alcohol become widely available during that decade, encouraged by a tax credit of 58 cents a gallon.

Once gasoline prices fell, interest in ethanol also fell as a result, and the tax credit in the United States was reduced, in 2005, to 47 cents a gallon.

More recently, concerns about dependence on foreign oil, as well as awareness of climate change have worked their way onto public and government agendas, resulting in a number of actions that have opened the doors for a resurgence of biofuel.

In 1992, the Energy Policy Act required car makers to offer models capable of using alternative fuels[12]. In 2006, the Renewable Fuels Standards (RFS) Program encouraged the use of ethanol and biodiesel with the goal of doubling their use by 2012. In 2007, the Energy Independence and Security Act (EISA) required the incorporation of 15 billion gallons of ethanol into the fuel supply by 2015 and 36 billion gallons by 2022. EISA also puts a cap on the amount of corn that can be allocated for fuel at 15 billion gallons so as not to overly interfere with the food supply[13]. Much of the rest is expected to come from cellulosic ethanol, which has been slow coming on line with the

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[11] Hammond, Allen: *Methanol at MIT: Industry Influence Charged in Project Cancellation*. Science magazine Vol. 190, 2002. Article available online at http://www.ourenergypolicy.org/wp-content/uploads/2011/11/1976_01_Science_Hammond_MethanolAtMITIndustryInfluenceProjectCancellation_w2002ThomasReedNote.pdf

[12] *Ethanol Fuel History:* http://www.fuel-testers.com/ethanol_fuel_history.html

[13] Siegel, Bob: *Should the US Halt Corn Ethanol Production During the Drought.* Available at http://www.triplepundit.com/2012/08/halt-corn-ethanol-production-during-drought/

remainder coming from biodiesel and other unspecified advanced biofuel that might include algae or other organisms[14].

[14] Siegel, Bob: *Can Synthetic Biology Produce Cheaper Biofuel? Should It?*
Available at http://www.triplepundit.com/2012/01/doe-lab-synthetic-biology-produce-cheaper-biofuel/

3.2.3. Bioenergy in Europe

As a matter of fact, residents in Europe have been familiar with bioenergy for at least over a century - the alcohol-based fuel resources used to be in abundance and untaxed. But it was not until 2003 that bioenergy consumption in Europe experienced a steep rise in quantity: In order to combat climate change and secure energy supply, the European Union has encouraged usage of bioenergy from forestry and agriculture, which serve as a crucial source of bioenergy for Europe. The Common Agricultural Policy encourages the use of bioenergy in rural areas and designates areas for forestry and agriculture whose purpose is to provide biomass for producing bioenergy. In the European Commission's introductory entry of bioenergy, the following beneficial features of bionergy are present:

- Bioenergy is one form of renewable energy among many from other sources (wind, solar, hydraulic, geothermal etc).
- Bioenergy, if produced sustainably, saves greenhouse gas emissions.
- Bioenergy accounts for more than two thirds of total renewable energy in the EU.
- Biomass for energy is mainly provided by forestry (which provides half of the EU's renewable energy), agriculture and organic waste. The share of agriculture – although still modest – is growing fast.
- Feedstocks for bioenergy are storable; bioenergy can thus be produced constantly and is a reliable source of energy.
- Biomass is amply available in most parts of Europe.
- Biomass can be either in solid, liquid or gaseous form and can be used to produce electricity, direct heating, or transport fuels.

In May 2003, bioenergy use in transport as a substitution to fossil fuel was promoted in Directive 2003/30/EC. Directive 2009/30/EC serves as an amendment to Directive

98/70/EC, implementing stricter environmental quality standards for a number of fuel parameters, further promoting widespread use of ethanol in petrol as a means of mitigating greenhouse gases emission and increasing the allowed biodiesel content to 7% in volume. Directive 2009/28/EC established most of the important targets for renewable energy sources in general and bioenergy in particular:

- By 2020, energy consumption from renewable resources should account for 20% of final energy consumption, and energy efficiency should be increased by 20%.
- Each Member State shall have a target of 10% of renewable energy sources used in transport.
- Minimum greenhouse gases reduction for bioenergy-based fuel is set at 35% and 50% from 2017 on; with new installations from 2017 on, the requirement is 60% reduction.

In January 2013, the European Commission suggested a Clean Fuel Strategy, which supported advanced biofuels produced from lignocellulosic feedstock and waste, as well as algae and other microorganisms. Furthermore, it recommended no additional public support for first-generation bioenergy fuels produced from food crops after 2020. In particular, the proposals suggested:

- To increase the minimum greenhouse gas saving threshold for new installations to 60% in order to improve the efficiency of biofuel production processes as well as discouraging further investments in installations with low greenhouse gas performance.
- To include indirect land use change (ILUC) factors in the reporting by fuel suppliers and Member States of greenhouse gas savings of biofuels and bioliquids;

- To limit the amount of food crop-based biofuels and bioliquids that can be counted towards the EU's 10% target for renewable energy in the transport sector by 2020, to the current consumption level, 5% up to 2020, while keeping the overall renewable energy and carbon intensity reduction targets;
- To provide market incentives for biofuels with no or low indirect land use change emissions, and in particular the 2nd and 3rd generation biofuels produced from feedstock that do not create an additional demand for land, including algae, straw, and various types of waste, as they will contribute more towards the 10% renewable energy in transport target of the Renewable Energy Directive.

In 2011, it was estimated that between 5.5 and 6.9 billion Euro was used to subsidize the use of conventional biofuel and fund the development of advanced biofuel. The main subsidy programs which support the bioenergy industry in Europe are:

- Market price support: A guaranteed market is provided for biofuel producers from Member States and prices are pushed upwards.
- Taxes exemption: Excises taxes that are normally applied to gasoline and diesel are partially or completely exempted off biofuel used in transportation.
- Research and development: The development of biofuel projects and technologies are frequently promoted.

The estimation for biofuel subsidy rate in Europe in 2011 is 15 - 21 Euro cents per liter of ethanol and 32 - 39 Euro cents per liter of biodiesel.

3.2.4. Bioenergy in Germany

Energy generated from biomass is one of the most abundant and diverse types of RES in Germany: It can be used in solid, liquid or gaseous form to produce electricity, heat and transportation fuel. In 2010, biomass-based energy accounted for 71% of total renewable energy consumption in Germany, and biofuel as a separate entity accounted for 13% of total renewable consumption[15]. Moreover, bioenergy accounted for 5.5% of total electricity consumption, 8.73% of heat demand and 5.8% of fuel consumption.

As Germany is strengthening its goal to reduce fossil fuel consumption and increase production of renewable energy, bioenergy production is now expanded. Although there are certain limits to the development of bioenergy, Germany can adapt any technical requirements for the processes. In the agricultural and forestry sectors, 12 million hectares of arable land, 5 hectares of grassland and 11 million hectares of woodland are reserved for the purpose of biomass production. As of 2009, sales of bioenergy reached 11.4 billion Euro. Further tatistical reports in 2011shows that the bioenergy industry was providing jobs for an approximate number of 125,000 people.

Currently, Germany is the top biodiesel consumer in the EU - energy generated from biodiesel in Germany reached 2,243.7 tons-of-oil-equivalent (TOE) in 2010. Diesel mixes with 5% of biodiesel (B5) was the first alternative transport fuel to be sold nation-wide in Germany, and it is sold at a lower price than conventional diesel. This is because Germany also followed the European Union's subsidy policy: As of 2010, Germany subsidized biodiesel products at the rate of 27 Euro cents per liter[16].

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[15] Federal Ministry of Food, Agriculture and Consumer Protection: *Bioenergy in Germany: Fact and Figures*, 2012. Avaiable at http://www.biodeutschland.org/tl_files/content/dokumente/biothek/Bioenergy_in-Germany_2012_fnr.pdf

[16] Janssen, R: *Biofuel Sustainability Policies in Germany*. Presented in the International Latin American – European Cooperation Workshop on "Sustainability in Biofuel Production", 2008. Presentation available at http://cenbio.iee.usp.br/download/eventobiotop/Rainer_Janssen-WIP.pdf

IV. Analysis

4.1. Correlation analysis between Germany's petroleum consumption, petroleum production and GDP per capita

In this part of the thesis, analyses concerning the relationship between the production and consumption of biodiesel (as a representative for bioenergy), petroleum (as a representative for fossil fuel) and GDP per capita.

The first analysis below is an attempt to draw a correlation between Germany's GDP per capita, primary production and consumption of petroleum. Data for the analysis is presented in the table below:

Table 1: GDP per capita, petroleum consumption and petroleum production in Germany from 2000 to 2010

(source: The European Statistics Center -http://epp.eurostat.ec.europa.eu/)

Year	**GDP per capita** *(Euro)*	**Petroleum consumption** *(thousands tons of oil equivalent - TOE)*	**Petroleum production** *(thousands tons of oil equivalent - TOE)*
2000	24,900	130,979.50	4,389.4
2001	25,500	133,834.70	4,354.0
2002	25,900	128,653.30	4,650.7
2003	26,000	124,808.80	4,780.6
2004	26,600	123,481.70	4,949.7
2005	27,000	121,460.00	5,217.4
2006	28,100	121,892.90	5,211.2
2007	29,500	110,096.00	5,185.7
2008	30,100	117,139.30	4,949.3
2009	29,000	110,545.20	4,495.6
2010	30,500	111,798.30	3,774.0

Figure 1: Petroleum production and consumption in Germany from 2000 to 2010 - data taken from Table 1)

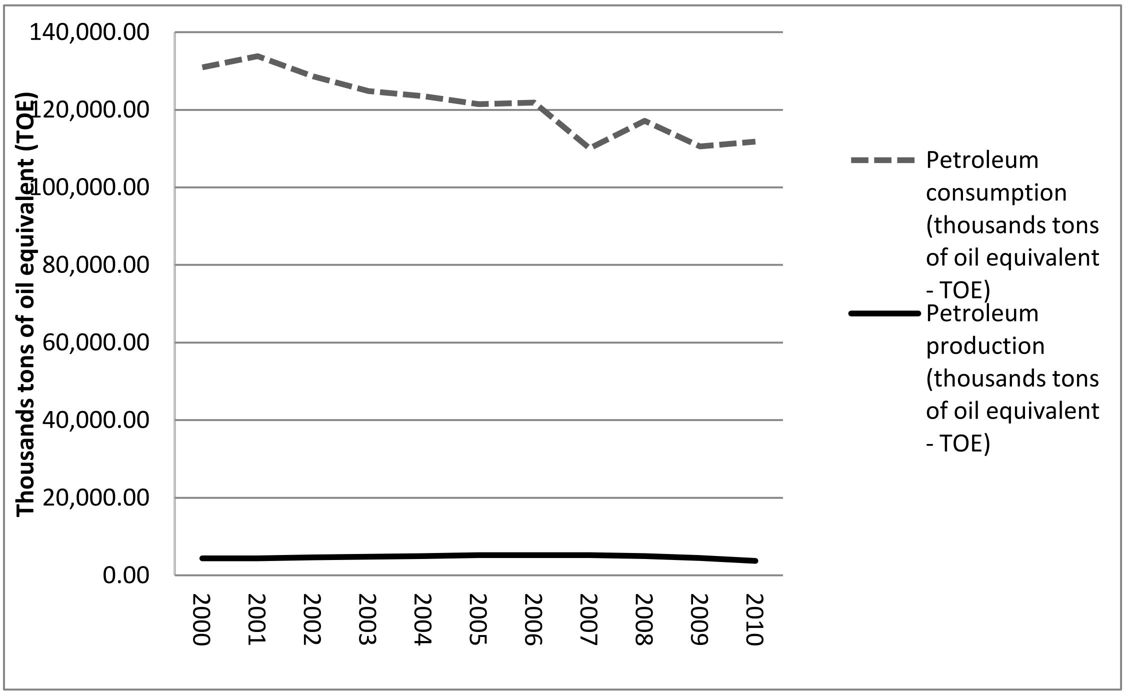
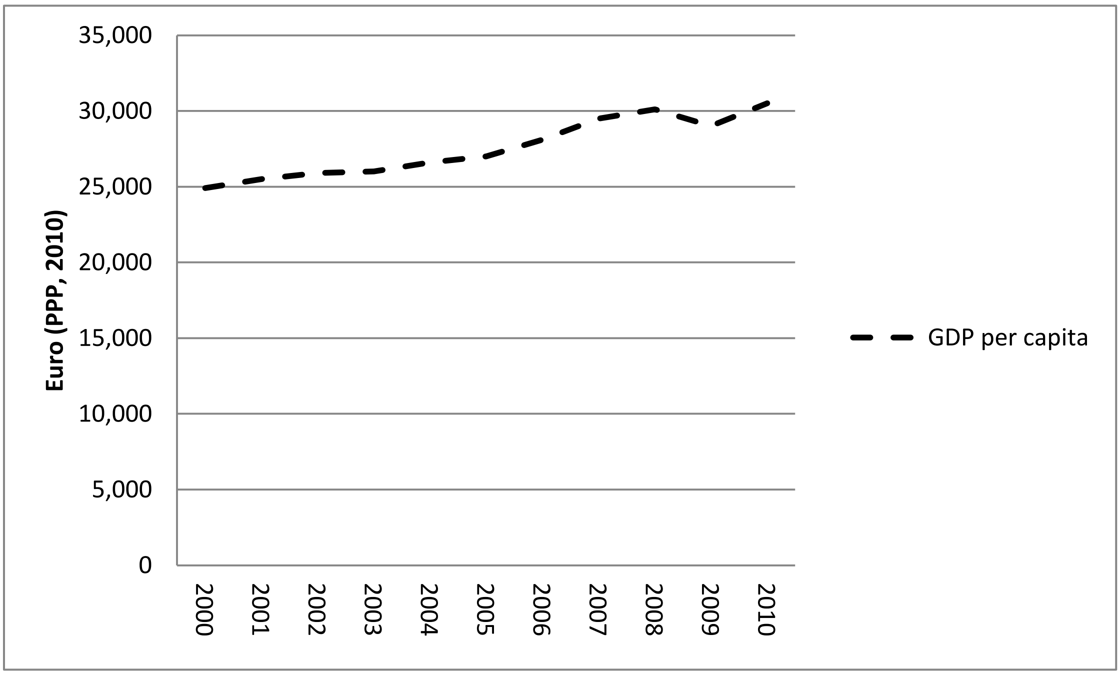


Figure 2: GDP per capita in Germany from 2000 to 2010 (data taken from Table 1)



Assuming that GDP per capita is correlated to both the primary production and consumption of petroleum via a regression model, the following model can be created:

$$y_t = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon_t$$

β_0: constant value
β_1, β_2: co-efficient
ε_t: random errors

with

y_t	...	*GDP per capita (in Euro)*
x_1	...	*petroleum products consumption (in TOE)*
x_2	...	*petroleum primary production (in TOE)*

In order to generate the model, GRETL is used to estimate the co-efficient with the Ordinary Least Squares (OLS) Method. The result is as follows:

Model 1: OLS, using observations 2000-2010 (T = 11)
Dependent variable: GDP_per_cap

	Coefficient	*Std. Error*	*t-ratio*	*p-value*
const	55707.7	5384.38	10.3462	<0.00001
Petroleum_consumption	-0.219732	0.035219	-6.2390	0.00025
petroleum_production	-0.315849	0.643897	-0.4905	0.63693

Mean dependent var	27554.55	S.D. dependent var	1974.013
Sum squared resid	6639969	S.E. of regression	911.0413
R-squared	0.829601	Adjusted R-squared	0.787002
F(2, 8)	19.47437	P-value(F)	0.000843
Log-likelihood	-88.81730	Akaike criterion	183.6346
Schwarz criterion	184.8283	Hannan-Quinn	182.8821
rho	-0.533333	Durbin-Watson	2.910657

With the estimated coefficients, the model now has the following formula:

$$\mathbf{y_t = 55707.7 - 0.2197x_1 - 0.316x_2 + \varepsilon_t}$$

Overall, an adjusted R-squared value of 0.787 indicates that 78.7% of the value of y_t can be explained by x1 and x2 using the model. Based on the resulting coefficient, it can be assumed that both explanatory variables negatively affect the dependant variable:

- If petroleum consumption increases by one thousand TOE, GDP per capita will decrease by 0.2197 Euro.
- If petroleum production increases by one thousand TOE, GDP per capita will decrease by 0.316 Euro.

Further statistical verification processes help determine whether the two allegedly explanatory variables significantly affect the dependant variable. The double-tailed t-test is used to test the significance of the independent variables, with the significance level $\alpha = 0.1$:

$$\text{t-critical}_{0.1/2}(11-3) = 1.860$$

For the purpose of testing the significance of the parameter, a null hypothesis needs to be formulated and tested. In this case, the null hypothesis H_0 is:

- H_0: Parameter is not significant ($\gamma = 0$, GDP per capita does not have a significant correlation with petroleum consumption and/or petroleum primary production)
- H_1: Parameter is significant (Reject H_0, GDP per capita has a significant correlation with petroleum consumption and/or petroleum primary production)

H_0 will be rejected if:

$$|\text{parameter's t-stat}| \geq \text{t-critical}$$

Using the t-stat of each parameter from the result generated by GRETL, we can now compare the values to test H_0:

Parameter	t-stat		t-critical	Reject H_0?
x_1 ($\gamma_1 = 0.218$)	$\|-6.2390\|$	>	1.860	Yes
x_2 ($\gamma_2 = 0.316$)	$\|-0.4905\|$	<	1.860	No

T-stat comparison shows that petroleum consumption (x_1) has a significantly correlative relationship with GDP per capita (y_t) while petroleum primary production (x_2) does not.

4.2. Correlation analysis between Germany's petroleum consumption, petroleum (crude oil) price and biodiesel consumption

Based on the previous analysis, we can conclude that GDP per capita and petroleum consumption in Germany are correlated. As bioenergy products, especially biodiesel, serve as an alternative to petroleum, it may be possible that their consumption amount may be correlated with petroleum consumption and by extension, affect GDP per capita. Another linear regression model is formulated to test this theory, with the assumption that petroleum consumption is affected by crude oil price and biodiesel consumption:

$$\mathbf{y_{t1} = \beta_3 + \beta_4 x_3 + \beta_5 x_4 + \varepsilon_{t1}}$$

β_3: constant value
β_4, β_5: co-efficient
ε_{t1}: random errors

with

y_{t1} ... *petroleum products consumption (in TOE)*

x_3 ... *biodiesel consumption (in TOE)*

x_4 ... *crude oil price (in USDs per barrel)*

Based on basic supply - demand principles, it is assumed that crude oil price will be negatively correlated with petroleum consumption, as the higher the price of a goods becomes, the lower its demand will be. Similarly, as biodiesel can be used as a subsitution for petroleum (especially in transportation), an increase in biodiesel consumption may eventually lead to a decrease in consumption of petroleum - which means that biodiesel consumption is also expected to be negatively correlated with petroleum consumption.

Data for the formulation of the model is as follows:

Table 2: Petroleum consumption, crude oil price (Brent - Europe) and biodiesel consumption in Germany from 2000 to 2010 [17]

Year	Petroleum consumption (Tons of oil equivalent - TOE)	Crude oil price (USD per barrel)	Biodiesel consumption (tons of oil equivalent - TOE)
2000	130,979.50	28.66	222.1
2001	133,834.70	24.46	311.0
2002	128,653.30	24.99	488.7
2003	124,808.80	28.85	709.7
2004	123,481.70	38.26	902.3
2005	121,460.00	54.57	1,596.9
2006	121,892.90	65.16	2,499.2
2007	110,096.00	72.44	2,943.6
2008	117,139.30	96.94	2,390.9
2009	110,545.20	61.74	2,156.7
2010	111,798.30	79.61	2,243.7

[17] Sources: The European Statistics Center - http://epp.eurostat.ec.europa.eu/ and the U.S Energy Information Administration - http://www.eia.gov/

The following graphs describe the data above:

Figure 3: Biodiesel consumption in Germany from 2000 to 2010 (data taken from Table 2)

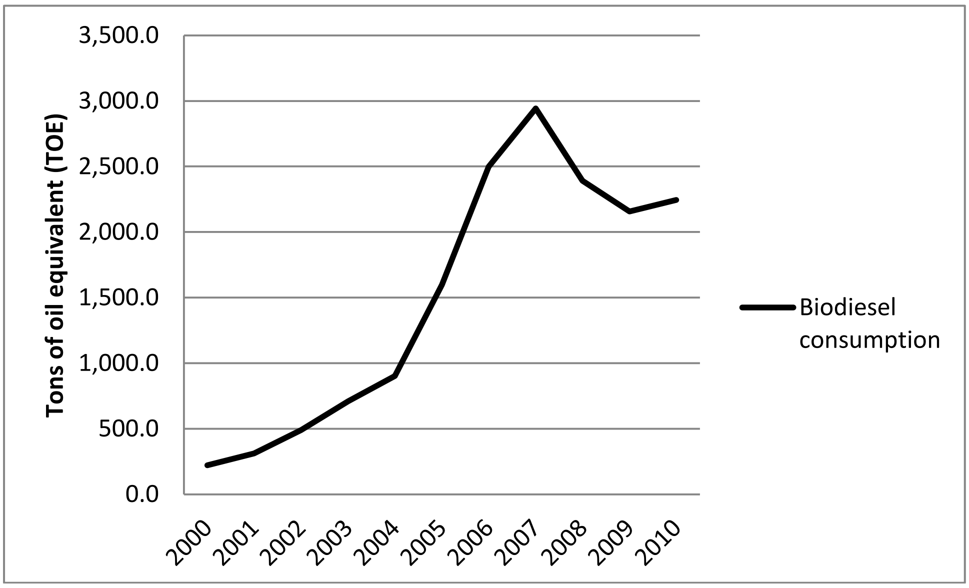
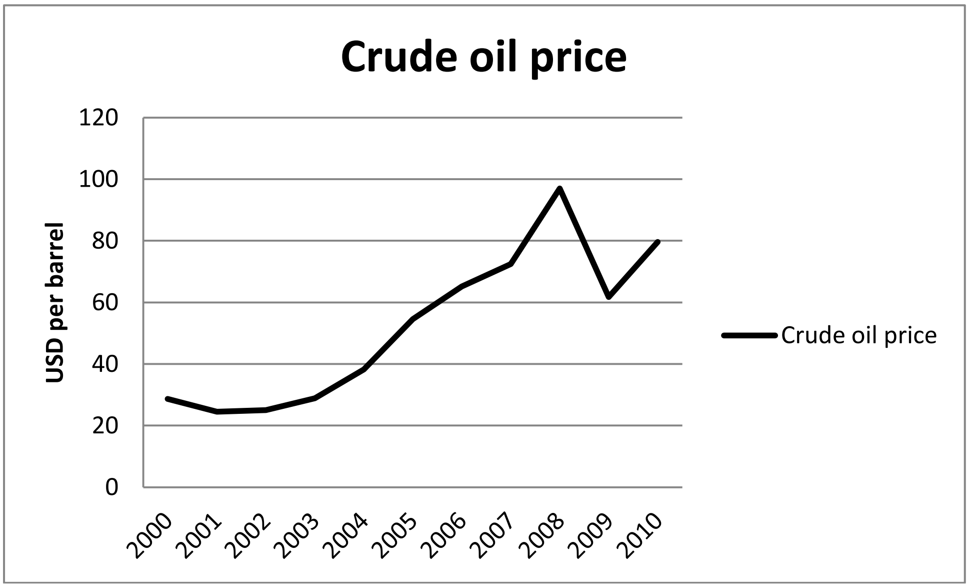


Figure 4: Crude oil price in Europe (Brent) (data taken from Table 2)



Using GRETL to estimate the model via the OLS Method, we have the following result:

Model 2: OLS, using observations 2000-2010 (T = 11)
Dependent variable: Petro_consumption

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	132388	3378.06	39.1905	<0.00001	***
oil_price	-8.87471	130.52	-0.0680	0.94746	
Biodiesel_consumption	-7.0738	3.27087	-2.1627	0.06253	*

Mean dependent var	121335.4	S.D. dependent var	8192.108
Sum squared resid	1.46e+08	S.E. of regression	4268.652
R-squared	0.782790	Adjusted R-squared	0.728487
F(2, 8)	14.41534	P-value(F)	0.002226
Log-likelihood	-105.8064	Akaike criterion	217.6128
Schwarz criterion	218.8065	Hannan-Quinn	216.8604
rho	0.090891	Durbin-Watson	1.726693

With the estimated coefficients, the model now has the following formula:

$$\mathbf{y_{t1} = 132388 - 7.074x_3 - 8.875x_2 + \varepsilon_{t1}}$$

Overall, an adjusted R-squared value of 0.728 indicates that 72.8% of the value of y_{t1} can be explained by x1 and x2 using the model. Based on the resulting coefficient, it can be assumed that both explanatory variables negatively affect the dependant variable, which matches the original assumption above:

- If biodiesel consumption increases by one thousand TOE, petroleum consumption will decrease by 7.074 TOE.
- If crude oil price increases by 1 USD per barrel, petroleum consumption will decrease by 8.875 TOE.

Further statistical verification processes help determine whether the two allegedly explanatory variables significantly affect the dependant variable. The double-tailed t-test is used to test the significance of the independent variables, with the significance level $\alpha = 0.1$:

$$t\text{-critical}_{0.1/2}(11-3) = 1.860$$

For the purpose of testing the significance of the parameter, a null hypothesis needs to be formulated and tested. In this case, the null hypothesis H_0 is:

- H_0: Parameter is not significant ($\gamma = 0$, petroleum consumption does not have a significant correlation with biodiesel production and/or crude oil price)

- H_1: Parameter is significant (Reject H_0, GDP per capita has a significant correlation with biodiesel production and/or crude oil price)

H_0 will be rejected if:

$$|\text{parameter's t-stat}| \geq t\text{-critical}$$

Using the t-stat of each parameter from the result generated by GRETL, we can now compare the values to test H_0:

Parameter	t-stat		t-critical	Reject H_0?
x_1 ($\gamma_1 = 0.218$)	|-2.1627|	>	1.860	Yes
x_2 ($\gamma_2 = 0.316$)	|-0.0680|	<	1.860	No

T-stat comparison shows that biodiesel consumption (x_3) has a significantly correlative relationship with GDP per capita (y_{t1}) while crude oil price (x_4) does not.

4.3. Trend analysis for biodiesel consumption

The purpose of this analysis is to predict future value of petroleum and biodiesel consumption in Germany based on a time trend. The same data sheet from previous analyses will be used for the trend analysis and prognosis will be compared to actual data in predicted years.

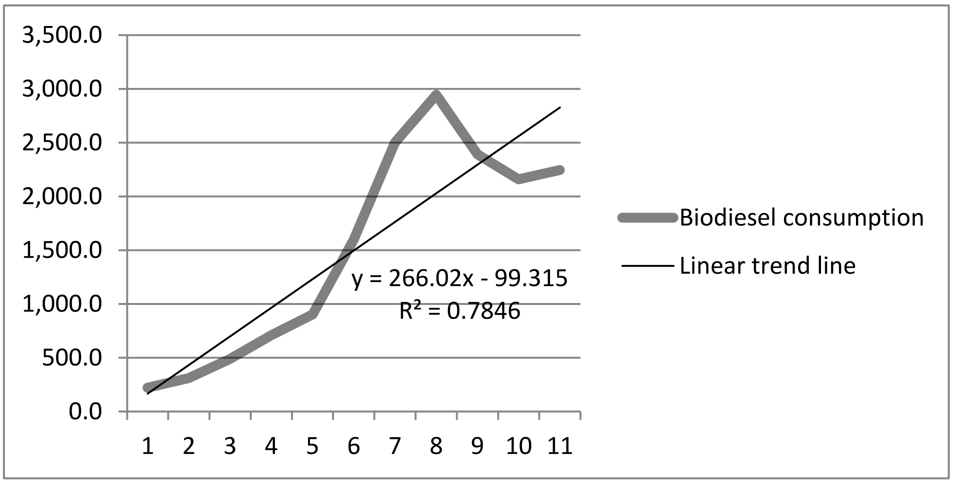
Each data sheet will be given 3 trend functions: one linear function, one quadratic and one cubic trend. The R-squared value from each trend line will be adjusted and compared based on this formula:

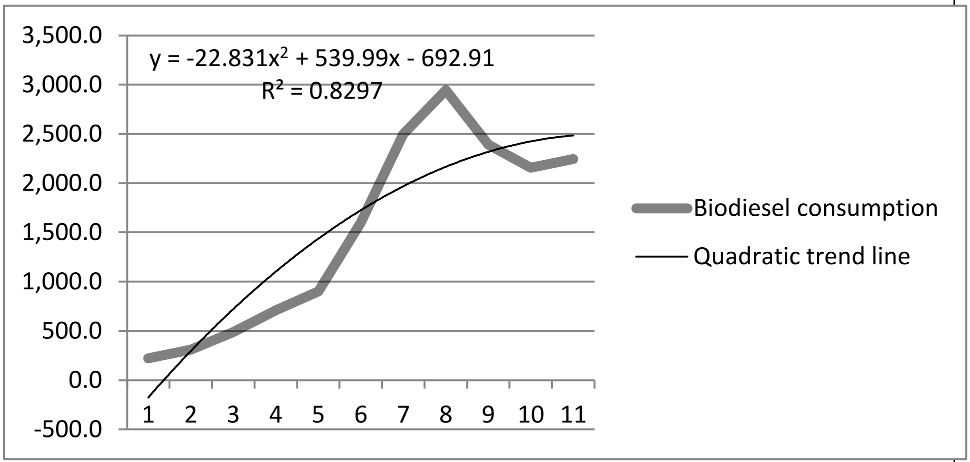
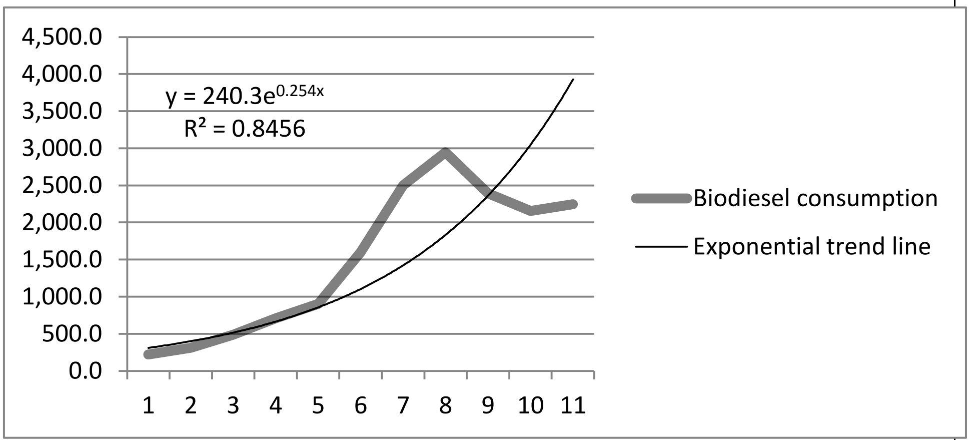
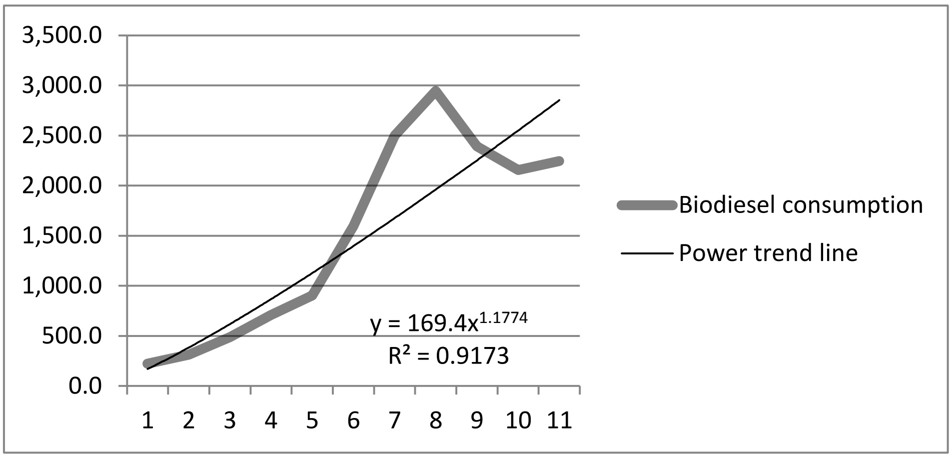
$$Adjusted.R^2 = R^2 - (1 - R^2)\frac{p}{n - p - 1}$$

In which: *n* is the sample size and *p* is the total number of variables.

Using Microsoft Excel for trend line generation and data from Table 2, we have the following model:

Table 3: Estimated trend line model for biodiesel consumption in Germany

Model with a linear trend line	

Model with a quadratic trend line	
Model with an exponential trend line	
Model with a power trend line	

With the R-squared values, we can have the following comparison:

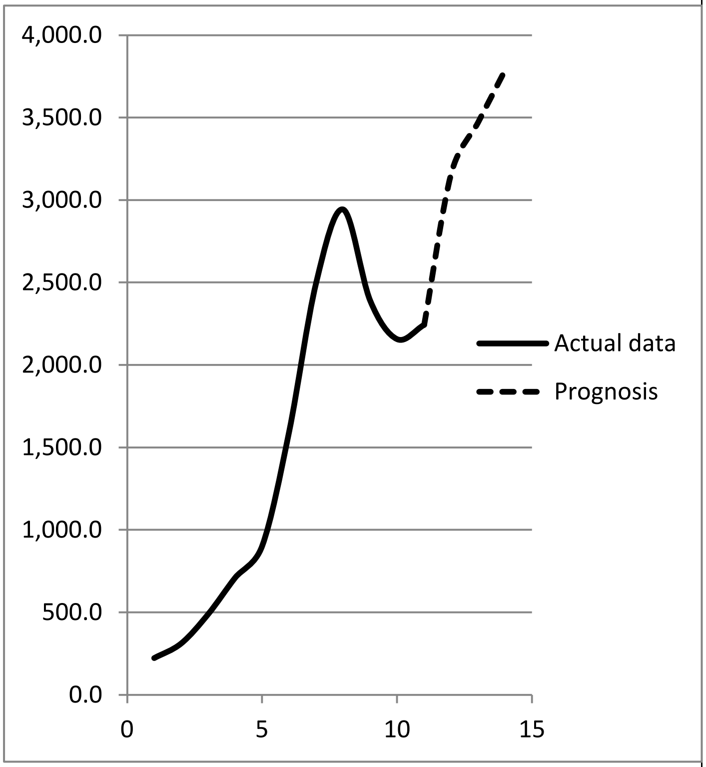
Table 4: Formulae and Adjusted R-square comparison

Function	Formula	R^2	n	p	Ad.R^2
Linear	$y = 266.02x - 99.315$	0.7846	11	2	0.73075
Quadratic	$y = -22.831x^2 + 539.99x - 692.91$	0.8297	11	2	0.78173
Expo.	$y = 240.3e^{0.254x}$	0.8456	11	2	0.807
Power	$\mathbf{y = 169.4x^{1.1774}}$	**0.9173**	**11**	**2**	**0.89663**

As the adjusted R-squared value of the power trend line is the highest, it will be chosen for forecasting.

Table 5: Forecasting model for biodiesel consumption in Germany in 2011, 2012 and 2013 using the power function[18]

Year	Time trend (x)	Biodiesel consumption (y)
2000	1	222.1
2001	2	311.0
2002	3	488.7
2003	4	709.7
2004	5	902.3
2005	6	1,596.9
2006	7	2,499.2
2007	8	2,943.6
2008	9	2,390.9
2009	10	2,156.7
2010	11	2,243.7
2011	*12*	*3158.94* ***(2143.5)***
2012	*13*	*3471.125* ***(2259.4)***
2013	*14*	*3787.604*



$y = 169.4x^{1.1774}$

$R^2 = 0.9173$

Adjusted $R^2 = 0.89663$

[18] The bolded number in 2011 and 2012 are real biodiesel consumption statistics in Germany (source: The European Statistics Center - http://epp.eurostat.ec.europa.eu/)

V. Result and Interpretation of the Result

In the first analysis, the result is a contradiction against the common assumption that an increase in energy consumption may lead to an increase in GDP. This is mostly due to the fact that Germany is one of the top ten petroleum consumers but not a prominent producer - they have to import crude oil to generate energy. And with the fact that GDP has import value as a negative factor, this may contribute to the negative trend found in the model. However, Germany is becoming less and less dependent on petroleum - this is reflected in the downward trend of petroleum consumption, as Germany is currently focusing on other renewable sources of energy.

The second analysis shows that petroleum consumption is not affected by crude oil price, but partially affected by biodiesel consumption. As mentioned before, biodiesel is a potential substitution product for petroleum, and with current subsidies and pro-bioenergy campaigns, it is speculated that biodiesel may eventually gain the upperhand over fossil-fuel-based diesel, thus making way for further development of bioenergy sources.

Overall, it can be concluded that an increased consumption of bioenergy may indirectly help increasing economic production in Germany (as a rise bioenergy consumption may lead to a decrease in fossil fuel consumption, which will eventually lead to an increase in GDP per capita as shown in the section 4.1.

The trend analysis reveals that biodiesel consumption in Germany may have a steep increase in the future, as prognosis has shown. However, when comparing the real data of biodiesel consumption in Germany in 2011 and 2012 with prognosis data, there appears to have a considerable gap between them. There are many reasons for the difference between reality and simulation data:

- Insufficiency of data: Biodiesel is still a relatively new source of energy in Germany. It may have been implemented earlier than other countries, but it was not until 2005 that biodiesel experienced a dramatic increase in utilization.

- Sole reliance on time trend as an independent variable.

- Unprecedented events: Such as a decrease in crude oil price in 2009 or negative news regarding the efficiency of bioenergy.

VI. Conclusion

As stated in the previous section, energy has a critical effect on economic production and growth, especially when the main sources of energy for economic production - fossil fuel - is becoming scarce. As Germany is one of the biggest oil importers in the world, this may become one of the relevant threats against the nation energy security, along with the government of Germany's decision to close all nuclear reactors by the end of 2022. As a result, numerous sources of renewable energy has been researched and applied successfully in Germany, among which bioenergy (especially bioethanol and biodiesel) has been given a lot of attention, as it is considered a clean energy resources which may reduce green house gases emission in the long run. Currently, Germany is the leading bioenergy consumer in Europe, and analyses provided above prove that there exists a possibility that increased use of bioenergy will help improving economic production.

However, there still exist risks in developing bioenergy production and usage. As processed bioenegy is most commonly used in its liquid form, it is most suitable to be used as substitute fuel for transportation. But the fact that certain vehicle models cannot run on bioenergy-based fuel, along with certain inconveniences and even risks in safety, has, to a certain degree, hindered the spread of bioenergy in Germany. Another issue is the competition for land usage: As second-generation bioenergy is still in the development stage and has proved to be harder to extract, first-generation bioenergy still remains the more practical sources of bioenergy. But as first-generation bioenergy is produced from crops, increased use in bioenergy may result in increased use of land for bio-energy crops cultivation, thus reducing the agricultural land for edible crop farming. This may seriously affect both food supply and ecology balance in the long run.

In conclusion, bioenergy has proved to be a useful energy resource whose use will help lessen the strains put on fossil fuel in Germany. However, the future development of bioenergy should be treated with caution - a misstep will result a serious blow not only to the economy, but also to our environment and our life.

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