



# A Study on Energy Efficiency and Economic Productivity of New Zealand's Agricultural Sector

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## Abstract

The realization of sustainable development depends on the efficient use of energy resources. Energy consumption productivity and efficiency are among important indices that play a critical role in explaining the behavior of energy consumption structure of different economic sectors, which in turn, plays a key role in policy making. From among economic sectors, the agriculture sector, as an important sector, depends on the consumption of energy as a factor underpinning agricultural production to a great extent. Thus, the present study tries to firstly calculate energy efficiency and productivity of agricultural sector; and then, investigate the relationship between production and energy consumption of New Zealand's agricultural sector using simultaneous equations system and two-stage least squares method. The annual data of New Zealand agricultural economics are used for the period of 1990-2017. The results showed that agricultural sector's energy consumption efficiency in New Zealand was mostly optimum according to energy efficiency index. In addition, estimation of energy equation revealed that the added value of agricultural sector had a positive influence on energy consumption growth. Among the other positively affecting variables, agricultural sector's labour and energy consumption in the prior period could be mentioned. The negative sign of capital stock in the equation reflects the fact that the higher the investment in agricultural sector, the lower the energy consumption.

**Keywords:**  
Agriculture, efficiency,  
energy, productivity, TSLS

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## INTRODUCTION

As one of the most important macroeconomic indices, high economic growth of countries has always been of great interest among politicians and economists. Given the dependence of different economic sectors including industries, agriculture, and services to energy, it is critical to understand how energy consumption by economic sectors influences high economic growth.

Energy is a production factor in economics. All production and service activities are made possible by energy consumption. Inadequate energy supply would interrupt all economic and social activities. The increasing dependence of societies on energy, due to the substitution of labour with machines and the use of energy-intensive technologies, has turned energy into a factor that influences the economic growth and development and plays a prominent role in the functioning of different economic subsectors (Asgharpur et al., 2008).

Sustainable development requires that available sustainable energy resources are supplied with no or minimum negative social impacts. The relationship between sustainable development and the use of resources, especially energy resources, is among the most important issues in humans' societies, and the realization of sustainable development is a matter of efficient use of energy resources (Rostami et al., 2018).

Nowadays, all developed and developing countries pay a special attention to productivity as a requisite for economic growth and gaining competitive advantage at the international scene. Awareness of productivity level and its variation trend over time can be of use to economic growth and welfare of the society. Productivity improvement means optimum, effective, and efficient use of all production resources including labour, capital, and energy (Ghanbari et al., 2014).

Currently, energy use efficiency is considered for reasons: the increased level of greenhouse gases and the scarcity of energy resources.

Among economic sectors, agricultural sec-

tor, quite heavily, depends on energy use to meet the growing food demand of the increasing world population and to supply adequate and appropriate food. Although various approaches have been considered for the boost of crop productions in the last few decades, the constraints like resource (including energy) limitations have drawn attention to the improvement of the productivity of production factors. Generally, since production inputs are scarce and limited, farmers and planners of agriculture sector have always been seeking approaches to increase production with smaller amount of inputs, especially scarcer inputs (Behbudi et al., 2009).

Miketa and Mulder (2003) examined energy productivity in 56 developed and developing countries in 10 industrial activities. They found that energy prices played a limited role in energy productivity growth and that technology change played an essential role in it.

In a study on the impact of energy on Turkey's agriculture productivity in 1971-2003, Karkacier et al. (2006) considered agriculture productivity as a log-log function of energy use and investment (gross additions of fixed assets). Results of regression analysis revealed that both variables had significant impacts and that there was a strong relationship between energy use and agriculture productivity. In addition, energy use elasticity was greater than zero, implying the intensity of energy use impact on the productivity of agriculture.

Po-Chi et al. (2008) investigated the growth of productivity of all agricultural sector factors in China's economics in 1990-2003 and found the main factor of total productivity growth to be technology progress and regional disparities. They also listed the causes of technology progress of agricultural sector as tax cut, public investment in R&D activities and infrastructures, and agriculture mechanization.

Ghanbari et al. (2014) first estimated energy productivity of Iran's agricultural sector by partial productivity index and then ap-

plied autoregressive distributed lag (ARDL) model to identify the most important factors underpinning energy productivity of agricultural sector. They found that average capital per unit energy use, real labour wage, average labour per unit energy, real price of oil products, and the ratio of electricity in total energy consumption had positive impact on short-term energy productivity. In addition, the ratio of electricity in total energy consumption showed a long-term positive, significant relationship with energy productivity of agricultural sector.

In an attempt to estimate the variation of energy efficiency distribution in automobile assembly industry, [Boyd \(2014\)](#) compared the assessment of the industry with boundary analyses and revealed that the industry had changed over time and that there was a great decline in the variance of fossil fuel efficiency distribution.

[Halkos and Tzeremes \(2013\)](#) studied the relationship between renewable energy consumption and economic efficiency using conditional data envelopment analysis estimators and non-parametric regressions for a sample of 25 European countries for 2010. Their results indicated a positive impact of renewable energy consumption on economic efficiency of the studied countries at low energy consumption levels, whereas no specific result was observed at higher energy consumption levels.

[Rasekhi et al. \(2016\)](#) worked on the economic and environmental efficiency of developing and developed countries. Their results of efficiency calculation revealed that developed countries had higher environmental and economic efficiencies than developing countries. Moreover, Granger causality test showed a bilateral relationship between environmental efficiency and economic efficiency. Also, estimation of the model by two-stage least squares method revealed a positive, bilateral relationship between these two efficiencies in the selected countries. Accordingly, it could be concluded that the enhancement of either efficiency would improve the other.

[Tahir and Faiza \(2017\)](#) explored the nature of relationship between energy efficiency and the level of economic activity in Pakistan during 1980-2016. They used Error Correction Model (ECM) for empirical analysis. Results of ECM predicted the existence of unidirectional causality from GDP to energy intensity. These findings supported conservation hypothesis on the basis of unidirectional causality running from output to energy efficiency. It is further observed that energy intensity in Pakistan is expected to increase further in the light of growing shares of industrial and services sectors in the GDP.

[Gökhan and Başak \(2018\)](#) defined total amount of input usage and did the economic comparison of wheat and sunflower production in Thrace Region in Turkey to determine the energy equivalent of these inputs. Energy use efficiency, energy productivity, specific energy and net energy in wheat production were calculated.

Agricultural sector is the largest economic sector of New Zealand and plays a significant role in production, exports, job creation, and food supply. The energy consumed by agricultural sector of New Zealand formed 42% of total energy consumption of all economic sectors of the country in 2017, so that agricultural sector used 1846 million kWh in this year – 47% higher than that of 2011. Since a considerable portion of energy is used by agricultural sector, higher energy productivity of this sector can greatly help the enhancement of energy productivity of whole country.

Given the fact that, presently, the energy sector plays a key role in realizing sustainable development and is regarded as one of the most important indicators of economic development, the present paper first looks at the theoretical framework, and then it describes energy efficiency and productivity over the period 1990-2017. Furthermore, the assumed production function is calculated by simultaneous equations system and two-stage least squares method in order to estimate the elasticities of components in production function of agriculture sector.

## METHODOLOGY

One primary requirement for a sound estimation is sound data. Thus, the nature of data included in statistical analysis and the model used for New Zealand's agricultural sector would play a significant role in the validity of analyses and the calculations of estimated coefficients. The statistical data for the period of 1990-2017 include the added value of agricultural sector, capital stock of agricultural sector, agricultural sector labor, and energy consumed by agricultural sector of New Zealand derived from FAO, the World Bank and NZ Stats (Statistics New Zealand). Data for labor are related to all human forces including experts, semi-expert, non-expert, male and female per annum. Data for capital stock shows annual gross fixed investment in agricultural sector on the basis of the current prices. Data for added value of agricultural sector are, also, expressed on the basis of the current prices. The consumed energy includes all kinds of energy consumed by agricultural sector including gas-diesel oil, motor gasoline, natural gas, electricity, and energy for power irrigation.

Undoubtedly, there is a close bilateral relationship between the use of energy demand function and production function method. Such a relationship can be studied by different tests; however, it is behaviorally defined by theories. An example of this relationship can be observed in production behavior functions in which energy is included as an input and production function is used to calculate its derived demand function.

Production functions express the technical relationship of production level with each input of the production and are a list (table or mathematical equation) that reflects the maximum output that can be produced from a certain set of inputs assuming *ceteris paribus*.

Bernt and Wood (1975) argue that energy is a production function with a weak, separable relationship with labor. They proposed the following production function:

$$Q_t = F[g(K, E), L] \quad (1)$$

Bruno and Sachs (1985), also, worked on the relationship between energy consumption and production level. They examined the relationship between imported raw materials and supply function of whole economics with a model in which the impacts of the increased oil price on the supply by whole economics were included. The outline of their function is as shown below:

$$Q_t = F(L, K, R) \quad (2)$$

where,  $Q$  denotes gross domestic production function that is assumed to depend on the inputs of capital ( $K$ ), labour ( $L$ ), and imported raw material ( $R$ ). Also, production return to scale was ascending and positive for each factor.

Since the Cobb-Douglas production function provides a better estimate than the translog and transcendental functions, because it allows the substitution between the factors during production, it has a more appropriate function form, and it has more significant variables and higher degrees of freedom, and also since its production elasticities are more reasonable for the agricultural sector as asserted by Azamzadeh Shouraki et al. (2011), Fallahi and Khalilian (2009), and Blitzer (1981), the Cobb-Douglas function can be introduced as the appropriate function for the agricultural sector of New Zealand.

To estimate the production function and the effect of energy inputs on agricultural sector production, it is imperative to pick a method that could estimate the significance with high explanatory power and could avoid such issues as non-stationarity, autoregression and autocorrelation. Accordingly, the factors resulting in these problems should be identified and modified so that reliable estimations can be acquired. The problems like statics and autoregression can be identified and solved by conventional methods and given the probability of concurrency among production variables expressed as the following general form (Berndt & Wood, 1975):

$$Q_t = A_0 I_t^{\alpha_1} E_t^{\alpha_2} K_t^{\alpha_3} e^{\alpha_4} \quad (3)$$

Since by theory, the variables energy consumption (E) and investment (K) are a function of production level, the following simultaneous equations can be applied:

$$\begin{aligned} Q_t &= A_0 L_t^{\alpha_1} E_t^{\alpha_2} K_t^{\alpha_3} e^{u_t} \\ E_t &= A_1 Q_t^{\gamma_1} L_t^{\gamma_2} K_t^{\gamma_3} E_{t-1}^{\gamma_4} e^{v_t} \\ K_t &= f(Q, K_{t-1}) \end{aligned} \tag{4}$$

In such a model, the interaction between energy and production can be derived and it can be specified how and how much either variable will change with the variation of the other variable and how much the recursive effect of this variation will be on the first variable. By deriving the logarithm of both sides, we have (Abbasi Nejad & Vafi Najar, 2004)

$$\log Q_t = \log A_0 + \alpha_1 \log L_t + \alpha_2 \log E_t + \alpha_3 \log K_t + u_t$$

$$\log E_t = \log A_1 + \gamma_1 \log Q_t + \gamma_2 \log L_t + \gamma_3 \log K_t + \gamma_4 \log E_{t-1} + v_t$$

$$\log K_t = \log f(Q, K_{t-1})$$

(5)

In this case, the coefficients of each variable reflect its elasticity against the dependent variable. This simultaneous equations system works in this way: If the amount of capital used in the production function is increased by, say, 1% (assuming that all other variables are constant), the production will change by  $\alpha_3$  per cent. Then,  $\log Q_t$  varies in Equation (2) proportionately resulting in  $\gamma_1$  per cent variation of energy consumption variable. Similarly,  $\log E_t$  varies in Equation (1), changing the production level. As the impact period extends, the variations gradually diminish and the modifications are terminated. The effect of modification continues as long as the initial evoked response is completely neutralized.

The initial impacts on production are usually imposed by production inputs. Nevertheless, production area sometimes becomes the changing factor due to the impacts of some exogenous or unpredicted factors. Then, demand for each input is naturally influenced.

Since our objective was to estimate the coefficients ( $\alpha_i$ 's), then we estimated the equation as a system using two-stage least squares method given the simultaneity of the variables.

The relationship between explanatory variable and error term is essentially the reason why it is necessary to use two-stage least squares method in the models. All in all, the relationships between the variables can be unilateral, bilateral and/or bilateral with the relation between residuals (Gujarati, 2003).

In addition, it should be noted that in statistical analyses for agricultural sector, energy consumption efficiency and energy productivity are calculated with the following equations:

$$\text{Energy efficiency} = \frac{\text{quantity of energy consumed in agricultural sector}}{\text{added value of agricultural sector}}$$

$$\text{Energy productivity} = \frac{\text{growth rate of energy consumed by agricultural sector}}{\text{rate of added value of agricultural sector}}$$

## RESULTS

### *Energy consumption in agricultural sector*

In terms of energy consumption, agricultural sector had the highest energy consumption rate among all economic sectors such that its share has never been less than 40% over the studied period. Among these years, the highest energy consumption rate was observed in 2017. Although energy consumption by agricultural sector has always demonstrated an ascending trend, it was not always resulted from the improvement of efficiency and the real growth of added value of this sector that naturally demands more energy. To the contrary, this increasing rate was partially associated with the loss of fuel consumption efficiency due to excessive depreciation of energy-consuming capital equipment.

This issue can be examined by energy consumption efficiency of agricultural sector that is the inverse of energy consumption intensity. Energy consumption intensity as calculated in Table 1 is a parameter that reflects the internal status of agricultural sector in

terms of energy use. A close look at the general trend of this index over the studied period shows the energy superiority of agricultural sector. Indeed, it reveals that energy consumption efficiency had a declining trend; for example, it was 0.000171 in 1991, implying that 0.000171 units of energy were consumed to produce \$1 added value. This index was increased to 0.000201 in 2017.

The point elasticity of energy consumption is another parameter that reflects the internal status of agriculture sector in Table 1. This elasticity is the division of consumed energy growth of the sector by added-value growth per annum. When it is greater than

unity, it shows that the energy consumption growth of agriculture is higher than the growth of added value so that more than 1% energy is consumed per 1% generated added value. The opposite holds when energy point elasticity is less than 1. Economically talking, this index is the most optimum if it is less than or, at most, equal to 1.

As a result, it can be concluded, from these parameters (Table 1 and Figure 1), that energy consumption efficiency of New Zealand's agricultural sector was mostly greater than 1 and optimum with slight fluctuations.

Table 1  
The Indices Showing the Status of Agricultural Sector

Year	Energy consumption growth of agricultural sector	Added value growth of agricultural sector	Point elasticity of energy consumption	Energy consumption intensity
1991	-7.15616	0.580113	-12.34	0.000171
1992	8.526775	-12.4005	-0.688	0.000158
1993	1.502119	17.01343	0.088	0.000195
1994	3.83607	0.225074	17.04	0.000169
1995	4.780723	7.152481	0.668	0.000175
1996	3.786754	8.8337	0.429	0.000172
1997	8.356757	0.385134	21.7	0.000164
1998	3.696911	-4.3545	-0.849	0.000177
1999	5.047423	4.783393	1.055	0.000191
2000	-2.6149	3.627142	-0.721	0.000192
2001	2.291688	-1.84706	-1.241	0.000180
2002	7.576024	-0.56455	-13.42	0.000188
2003	-0.62996	11.2131	-0.056	0.000203
2004	-3.31906	-3.07156	1.081	0.000182
2005	6.407894	5.187851	1.235	0.000181
2006	1.352408	0.200283	6.752	0.000183
2007	12.37753	-15.8158	-0.783	0.000185
2008	-4.56626	9.576573	-0.477	0.000248
2009	-5.19883	0.884796	-5.876	0.000216
2010	-3.63321	-7.88437	0.461	0.000203
2011	3.366232	12.27047	0.274	0.000212
2012	2.516221	5.624784	0.447	0.000195
2013	2.465866	1.958054	1.259	0.000189
2014	-0.97632	8.171956	-0.119	0.000190
2015	1.64238	1.34974	1.223	0.000188
2016	0.81905	1.02551	0.802	0.000194
2017	1.93746	3.51947	0.549	0.000201

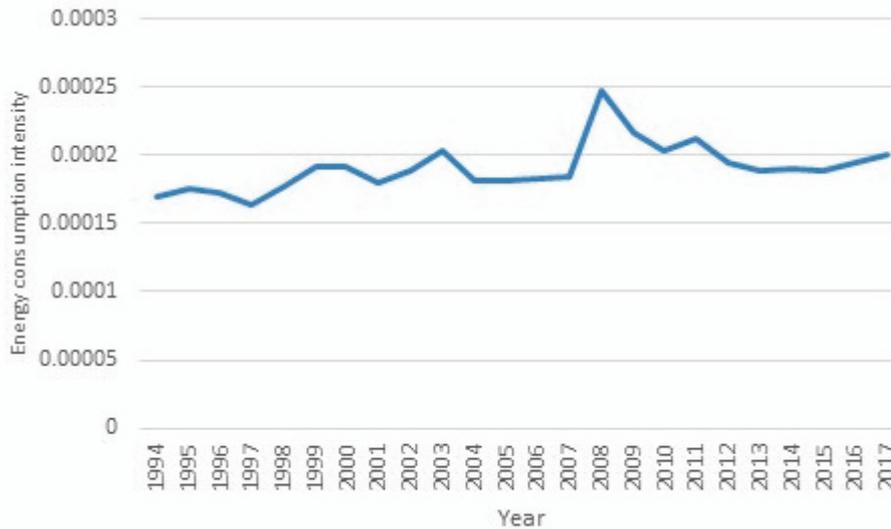


Figure 1. Indices Energy consumption intensity

**Reliability test of model variables and estimation of production function and energy**

Since simultaneous equations system structurally differs from multivariate regressions, it may not supply the classic assumptions governing multivariate regressions. For example, a property of simultaneous equations system is that the dependent variable in an equation emerges as the explanatory variable of another equation of the system. Such an explanatory variable may emerge in another equation of the system. The explanatory variable may be correlated with the residual term of the question in which it has been included as the explanatory variable, and the correlation of explanatory variable with the residual term of an equation violates the classic assumption  $cov(ui,xi) = 0$ . In these conditions,

the application of conventional least squares estimators leads to results that are not only biased but also inconsistent. In other words, even if the sample size approaches infinity, conventional least squares estimators will not be equal to the real values of the society (Gujarati, 2003). Therefore, to avoid the generation of diagonal and unreal estimations of coefficients, simultaneous equations system and two-stage least squares method were applied. This method estimates the intended model equations simultaneously, so that the bias induced by the relationships between variables is eliminated.

Table 2 summarizes the results of reliability. It shows that the studied time series were not stationary which were become stationary at first difference.

Table 2  
The t-Stat Results of Augmented Dickey Fuller Tests

Variables	At level		At first difference		Decision
	Intercept	Intercept & trend	Intercept	Intercept & trend	
Added value	-1.27	-2.83	-6.46 *	-4.67 *	I(1)
Energy consumption	-3.06	-0.49	-3.46 **	-5.93 *	I(1)
Capital stock	-2.63	-3.24	-6.36 *	-6.25 *	I(1)
Labour	-1.32	-1.44	-5.56 *	-4.21 **	I(1)

\*P<0.1, \*\* P<0.05

Since all research variables were non-stationary, the time series were differentiated to make them stationary. However, the essential problem in using the difference of variables is that invaluable information is lost about the level of variables; therefore, we used Engle-Granger test at this stage (Table 3). Cointegration means that despite the fact that

the times series are individually non-stationary, the linear combination of two or more (non-stationary) time series variables can be stationary. In fact, there exists a long-term equilibrium relationship that the economic system moves towards over time. Results of this test showed the long-term convergence of research variables.

Table 3  
Results and Engle-Granger Test

Variable	ADF statistic	Critical values		
		10%	5%	1%
RESID	-6.87	-2.65	-3.02	-3.80

According to the results of the tests, the equations of the system were estimated with two-stage least squares method. Result of the estimation of agricultural sector production function is shown below in which *AVV* denotes added value of agricultural sector, *E* de-

notes energy consumption by agricultural sector, *K* denotes investment, and *L* denotes labor.

$$\log VAA_t = 2.22 + 0.28 \log E_t + 0.21 \log K_t - 0.38 \log L_t$$

Table 4  
Results of Estimations of Agricultural Sector Production Function Derived from Two-Stage Least Squares Model

Variable	Coefficient	t-statistic
Interception (C)	2.22	3.82 *
Logarithm of energy consumption (E)	0.28	7.13 *
Logarithm of capital stock (K)	0.21	1.68 ***
Logarithm of labour (L)	-0.38	-2.83 *
R <sup>2</sup> = 0.96		

Note: \* P<0.1, \*\*P<0.05 \*\*\* P<0.01

Results of estimation of production equation of Table 4 in system reveal that from among the three variables of the equation, the variables of energy consumption and capital are positively related to the production. The coefficient of consumed energy is 0.28 that is the energy input elasticity in agricultural sector and shows that production varies

by 0.28% per 1% variation in energy input. Energy input elasticity is less than one, and so, energy can be considered as inelastic input (against production). The variable of labor has a negative relationship with production. The negative sign of labor expresses the negative return of labor in this sector such that the production of agricultural sec-

tor is decreased by 0.38% per 1% higher labor unit. As the sum of coefficients show, agricultural sector is faced with a decreasing return to scale implying that if all inputs are uniformly increased, production will increase to a lesser extent.

Results in Table 5 indicate that the value

added of agricultural sector has a positive impact on energy consumption growth. It means that 1% increase in value added of agricultural sector has resulted in 0.37% higher energy consumption over the studied years.

Table 5

*Results of Estimation of Energy Function Derived from Two-Stage Least Squares Model*

Variable	Coefficient	t-statistic
Interception (C)	-5.09	-2.55 *
Logarithm of added value of agricultural sector (AVV)	0.37	2.19 *
Logarithm of capital stock (K)	-0.75	-2.05 *
Logarithm of labour (L)	1.07	0.34
Logarithm of lagged energy consumption (E <sub>t-1</sub> )	0.65	8.4 *

R<sup>2</sup> = 0.99

\* P<0.1

One another positively affecting variable in Table 5 is the labor of agricultural sector and energy consumption of the prior period. The negative sign of capital stock in the function expresses that the higher the investment in agricultural sector, the higher the production potential by exploiting more facilities and production inputs. Accordingly, it can be concluded that the capital stock in agriculture enjoys a privileged status as compared to other production factors, given its potential for conversion to other production factors, so that sound exploitation of capital and its combination with other production factors and optimum use of limited resources will pave the way for considerable improvement of production capacity and, consequently, will make it possible to cut energy consumption.

### CONCLUSION

Energy is a production factor in economic systems. Given the role and significance of energy in growth and development of nations and different economic sectors, the present

work studied energy consumption of New Zealand's agricultural sector over the period 1990-2017. Indices showing the internal status of this economic sector's energy consumption including energy consumption intensity, consumed energy efficiency and productivity were estimated. The intensity of energy consumption was found to be, on average, increasing over the studied period. Despite the ascending trend of energy consumption intensity, energy consumption efficiency – which is the inverse of energy consumption intensity – was mostly optimum over the studied period in spite of some fluctuations. Energy point elasticity, which is derived from the division of energy consumption growth rate by added value growth rate, exhibited an increasing rate, though it had different values over the studied period.

According to the results of the estimation of system equations, most variables are significantly related to the endogenous variable. To be more exact, from among three variables of the first equation, energy consumption vari-

able and production have a positive relationship. Secondly, the labor variable has a negative relationship with the production. And finally, the capital stock variable does not have a significant relationship with the production of agricultural products.

In the second equation with four explanatory variables, the variables of production level, labor and energy consumption in the prior period are positively related to energy consumption, and the variable of capital stock is negatively related to energy consumption.

All in all, the results of the present study are consistent with Ghanbari et al. (2014), Asgharpur et al. (2008) and Tahir & Faiza (2017) confirming the effectiveness of energy use input on the production of the agricultural sector.

According to the results, the following recommendations can be drawn:

Since the variable of labor, as per energy unit, has the highest effect on energy productivity, a greater number of and more skillful work forces should be hired for this sector and the existing labor should be trained in order to maximize the productivity.

Given the negative impact of capital inventory, as per energy unit, it is recommended to invest more in low-consumption agricultural machinery and industries.

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