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Dynamic Interaction between Energy Consumption, CO2 Emissions and Economic Growth in Malaysian Industrial Sector: An Aggregate and Disaggregate Analysis

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Abstract

Energy is a crucial factor of production, especially for the industrial sector where it is playing a vital role in substituting labour input in technological processes. Energy is still crucial for advancing Malaysia's socioeconomic development and prosperity as well as for propelling the industrial revolution. This study explores the causal relationships between real income (Y), energy consumption (both aggregate and disaggregate), CO2 emissions (both aggregate and disaggregate), and employment in Malaysia's industrial sector during the period of 1982-2019. By applying the time-series econometric techniques, this study discovered unidirectional causality from Y, CO2 emissions, and employment to gas energy consumption over the long run. In the short run, the study identified causality from (*i*) employment to energy consumption for coal, oil, and all aggregates; (*ii*) Y to CO2 emissions for coal and aggregates; (*iii*) Y to energy consumption for coal and oil; and (*iv*) employment to CO2 emissions for aggregates. Furthermore, there is a bidirectional short run causal relationship between Y and aggregate energy consumption as well as between coal energy consumption and CO2 emissions.

Keyword: Energy Consumption, Carbon Dioxide Emission, Industrial Sector

Introduction

Since 1970, Malaysia had transformed from an agricultural economy into an industrial economy. In 1985, Industrialisation Plan had been implemented by the Malaysian government which means that Malaysia was focusing on the industrial sector (Tan and Tan, 2018). By 1990, Malaysia had met the criteria as a Newly Industrialized Country (NIC) which means 30 per cent of exports consisting of manufactured goods (Hussin and Ching 2013, Azer, et al., 2016). Until today, the industrial sector still plays a key role in the Malaysian economy. In Malaysia, there is high economic growth, especially the industrial sector contribution was more than 39 per cent of the total gross domestic product (GDP) in 2022 (World Bank, 2024).

Energy is a crucial factor of production, especially for the industrial sectors (Stern, 2000). The importance of the usage of energy to substitute the labour input in technological processes is usual for all the industrial sectors (Pokrovski, 2003). In that sense, the role of energy remains a vital ingredient not only for the industrial revolution but further enhanced the socio-economic prosperity and development in Malaysia (Lau et al., 2016). In another word, Malaysia has a high rate of energy demand due to the development of the country. Looking into the energy sector, most of the energy sources in Malaysia come from fossil fuels. According to British Petroleum (BP) (2022), fossil fuels (natural gas, crude oil and coal and coke) are contributed more than 91 per cent of the total primary energy consumption in 2021. This proves Malaysia is a country that is heavily dependent on fossil fuels for economic growth. However, global warming and green-house gas emissions are become the central issues in Malaysia because of dependency on fossil fuels. This supported by the BP (2022) shows that Malaysia's CO2 emission rose from 209.8 million tonnes to 238.6 million tonnes in the last decade (2011 – 2021). It means that Malaysia's CO2 emission is increasing around 2.9 per cent every year. On the assumption that Malaysia still relies on fossil fuels to meet the growth in its energy demand and intrinsically, its emerging economy is expected to increase the CO2 emissions, and this will cause serious concerns about its effects on the environment. Therefore, Malaysia is facing the challenge of increasing pollution levels in the exchange of achieving economic growth. The contribution of this research outcome is able to determine the relationship between GDP, aggregate and disaggregate energy consumption and CO2 emissions as well as labour force in Malaysian industry sector, which these relationships will help Malaysia to further increase our energy efficiency and our nation's environmental quality. Based on the research outcomes, Malaysia can efficiently draft future policies to ensure better environmental quality and to utilise fossil fuels as well as to reduce inefficiency or unnecessary wastage of energy. A low level of CO2 emissions may exert positive externalities to the economy, such as increasing our productivity.

Therefore, many studies have previously investigated the impacts of energy consumption, economic growth, labour force, and CO2 emissions in various countries, including aggregate and disaggregate analysis. For example, Menyah and Wolde-Rufael (2010), Ameyaw and Yao (2018), Sulaiman and Abdul-Rahim (2018), Mensah et al. (2019), Nskengfack and Fotio (2019), Tong et al (2020), Osobajo et al (2020), Nain et al (2020), Valadkhani et al. (2019), Alsarayreh et al (2020), Apinran et al (2021), Mitic et al. (2022), Zhou (2023), Dissanayake et al. (2023). Aditionally, there has a number of studies have examined the relationship of energy consumption, economic growth, and CO2 emissions in Malaysia, such as, Ang (2008), Saboori and Sulaiman (2013), Chandran and Tang (2013), Begum et al (2015), Islam et al. (2017). To the best of researcher's knowledge, the only handful of studies focused on industrial sector. Besides, energy consumption in Malaysian industrial sector has been studied by Tan and Tan (2018). The study looks into the causal relationship between real GDP, energy consumption and CO2 emissions in Malaysian industrial sector. Tan and Tan (2018) only focused on aggregate analysis. Hence, the gap in the literature has been highlighted in this research study by not only considering aggregate industrial sector but also including disaggregate energy consumption, disaggregate CO2 emissions and labour force in the model using Malaysia's industrial sector as the case study.

This study aims to investigate the relationship between economic growth (GDP), energy consumption by aggregate and disaggregate, CO2 emissions by aggregate and disaggregate and employed persons in Malaysia's industry sector by using time series data analysis. To accomplish the objective, rigorous systematic statistical tests of integration, cointegration, and causality are offered in the present work. This research paper is organised as follows: Section 1 provides the detailed introduction and background of the study, Section 2 describes the empirical approach and data adopted in the paper, Section 3 reports the empirical results and Section 4 concludes the paper.

Data, Model and Methodology

This study covers the annual data period from 1982- 2019. The data of aggregate energy consumption (total energy consumption in industrial sector), disaggregate energy consumption (coal and coke - COAL, crude oil and petroleum - OIL, and gas - GAS energy consumption in industrial sector), CO2 emissions by industrial sector (aggregate and disaggregate) were obtained from Asia-Pacific Economic Cooperation (APEC) energy database. Real industry value-added as a share of GDP was obtained from World Bank's World Development Indicators. Employed person in industrial sector was been sources from various issues of *Economic Indicators – Time Series* published by Department of Statistics Malaysia. All variables are converted into natural logarithm prior to estimation.

The empirical model in this study is modified from the original traditional energy function (Kraft and Kraft, 1978) as follows:

$$Y=f\,(EC) \qquad (1)$$

where *Y* represents GDP and *EC* is energy consumption.

Meanwhile, introducing a pollution variable (CO2 emission) and employed persons by industry sector into the model as control variables can be specified as follows:

$$Y=f\,(EC, CO2, EMP) \qquad (2)$$

where *Y* represents GDP, *EC* is energy consumption by industry sector and *CO2* is CO2 emission by industry sector as well as *EMP* is employed person by the industry sector. Therefore, we form the long run relationship production function between four-dimensional systems in a linear logarithmic quadratic form.

$$LYt=\alpha+\beta1LECt+\beta2LCO2t+\beta3LEMPt+\varepsilon t \; LYt=\alpha+\beta1LECt+\beta2LCO2t+\beta3LEMPt+\varepsilon t \qquad (3)$$

where LYt is natural logarithm of GDP by industry sector, $LECt$ is natural logarithm of energy consumption industry sector. $LCO2t$ is natural logarithm of carbon dioxide (CO2) emissions by industry sector. $LEMPt$ is natural logarithm of employed persons by industry sector and εt is error term. To examine the separate effect of these types of energy consumption (disaggregate energy consumption) on economic growth, CO2 emissions (disaggregate CO2 emissions) and employment and on this basis of Equation (3), this study disaggregates total energy consumption into coal and coke, crude oil and petroleum products, as well as gas, as follows.

i. The model for coal and coke consumption in Malaysian industry sector is as follows:
$LYt=\alpha+\beta 1LCOALt+\beta 2LCO2t+\beta 3LEMPt+\varepsilon t$ (4)

ii. The model for crude oil and petroleum consumption in Malaysian industry sector is as follows:
$LYt=\alpha+\beta 1LOILt+\beta 2LCO2t+\beta 3LEMPt+\varepsilon t$ (5)

iii. The model for gas consumption in Malaysian industry sector is as follows:
$LYt=\alpha+\beta 1LGASt+\beta 2LCO2t+\beta 3LEMPt+\varepsilon t$ (6)

This empirical study has two specific objectives. The first objective is to examine the long run relationship between GDP, EC (aggregate and disaggregate), CO2 emissions (aggregate and disaggregate) and employed persons in the industry sector. The second objective is to examine the existence and different direction of causation in short and long run between the variables. The testing procedure entails four steps. The first step is to employ unit root tests proposed by Dickey and Fuller (1979)- ADF unit root test and Kwiatkowski, Phillips, Schmidt and Shin (KPSS) (1992) unit root test to test whether the variables contain a unit root. The second step is to test whether there is a long run cointegrating relationship between the variables, using Johansen and Juselius cointegration test proposed by Johansen and Juselius (1990). Furthermore, there always exists a corresponding error correction representation in the presence of cointegration (or long run cointegrating relationship). In other words, if a vector autoregressive (VAR) system is cointegrated, the Granger causality test may be conducted in the environment of vector error correction model (VECM). Otherwise, the analyses may be conducted as a standard first difference VAR model.

Before testing for cointegration, it is necessary to ascertain the order of integration for each variable. An ADF test (Dickey and Fuller, 1979) and KPSS test (Kwiatkowski et al., 1992) on the series of Y_t, EC_t (include the disaggregate energy consumption) and $CO2_t$ (include the disaggregate CO2) as well as EMP_t were conducted. The results which are made available upon request suggest the existence of unit root or non-stationarity in level or I (1) for these variables. The findings have the same order of integration allowed the researchers to proceed with the Johansen and Juselius (1990) cointegration analysis.

In the presence of cointegration, there always exists a corresponding error-correction representation. In other words, if a vector autoregressive (VAR) system is cointegrated, the Granger causality test (Granger, 1988) must be conducted in the environment of vector error-correction model (VECM). In this study, the three-dimensional VECM systems were determined as follows:

ΔYt=α1+∑pi=1β1iΔYt−i+∑pi=1ω1iΔECt−i+∑pi=1η1iΔCO2t−i+∑pi=1∂1iΔEMPt−i+λ1ECTt−1+e1t (7)

ΔECt=α2+∑pi=1ω2iΔECt−i+∑pi=1β2iΔYt−i+∑pi=1η2iΔCO2t−i+∑pi=1∂2iΔEMPt−i+λ2ECTt−1+e2t (8)

ΔCO2t=α3+∑pi=1η3iΔCO2t−i+∑pi=1β3iΔYt−i+∑pi=1ω3iΔECt−i+∑pi=1∂3iΔEMPt−i+λ3ECTt−1+e3t (9)

ΔEMPt=α1+∑pi=1∂4iΔEMPt−i+∑pi=1β4iΔYt−i+∑pi=1ω4iΔECt−i+∑pi=1η4iΔCO2t−i+λ4ECTt−1+ e4t (10)

Where Δ denotes the first difference operator, Y_t is real industry value-added as a share of GDP, EC_t is aggregate and disaggregate energy consumption in the industrial sector, $CO2_t$ is CO2 emission (aggregate and disaggregate), EMP_t is employed person and *ECT* is the error-correction term. e_{it} is the disturbance term, *p* denotes the lag order and λ_i are the coefficients of ECT. From the equations (7)-(10), there is Granger causality runs from *ΔEC* to *ΔY* if the null hypothesis $\omega_i = 0 \forall_i$ is rejected through a Wald test. Likewise, if the null hypothesis $\eta_i = 0 \forall_i$ is rejected implies that there is Granger causality runs from *ΔCO2* to *ΔY*. Similarly, if the null hypothesis $\partial_i = 0 \forall_i$ is rejected implies that there is Granger causality runs from *ΔEMP* to *ΔY*. The same testing procedure can be applied to examine the causalities from *ΔY to ΔEC* or *ΔCO2* or *ΔEMP* in Malaysian industrial sector.

Empirical Results

It is necessary to ascertain the order of integration for each variable before testing for cointegration. An ADF test (Dickey and Fuller, 1979) and KPSS test (Kwiatkowski et al., 1992) on the series of *Y*, EC_t (aggregate and disaggregate energy consumption by the industrial sector), $CO2_t$ (aggregate and disaggregate CO2 emissions by the industry sector), and EMP_t were conducted. The results which are made available upon request suggest the existence of unit root or non-stationarity in level or I (1) for these variables. The findings that the all the variables have the same order of integration allowed to proceed with the Johansen and Juselius (1990) cointegration analysis.

The cointegration results are presented in Table 1. The null hypothesis of no cointegrating vector (r = 0) was soundly rejected at the 5 per cent significance level for the case of GAS only, implying that the Y, EC for gas in the industry sector, CO2 by the industry sector and EMP do not drift apart and share at least a common stochastic trend in the long run. For the remaining energy domains (aggregate, OIL, COAL), no long run relationship was detected.

Table 1
Johansen-Juselius Cointegration Test Results

Null	Alternative	λmax		Trace	
		Unadjusted	95% C.V	Unadjusted	95% C.V
Aggregate Energy Consumption (Industry Sector)					
				k = 1 r = 0	
r = 0	r = 1	24.1272	27.5843	38.5388	47.8561
r ≤ 1	r = 2	9.3583	21.1316	14.4116	29.7971
r ≤ 2	r = 3	4.6848	14.2646	5.0533	15.4947
r ≤ 3	r = 4	0.3685	3.8415	0.3685	3.8415
Coal and Coke (COAL)					
				k = 1 r = 0	
r = 0	r = 1	18.1056	27.5843	28.8661	47.8561
r ≤ 1	r = 2	5.856	21.1316	10.7605	29.7971
r ≤ 2	r = 3	4.1477	14.2646	4.9045	15.4947
r ≤ 3	r = 4	0.7568	3.8415	0.7568	3.8415
Crude Oil and Petroleum Products (OIL)					
				k = 1 r = 0	
r = 0	r = 1	23.0593	27.5843	44.0962	47.8561
r ≤ 1	r = 2	17.2733	21.1316	21.0369	29.7971
r ≤ 2	r = 3	3.5464	14.2646	3.7636	15.4947
r ≤ 3	r = 4	0.2172	3.8415	0.2172	3.8415
Gas (GAS)					
				k = 1 r = 1	
r = 0	r = 1	113.7610**	27.5843	137.0539**	47.8561
r ≤ 1	r = 2	17.4083	21.1316	23.2929	29.7971
r ≤ 2	r = 3	5.158	14.2646	5.8846	15.4948
r ≤ 3	r = 4	0.7266	3.8415	0.7266	3.8415

Notes: k is the lag length and r is the cointegrating vector and r is number of cointegrating vectors that are significant under both tests. Asterisks (**) denotes significant at 5 percent significance level.

Results for VECM were portrayed in Table 2. First, short run causality was not detected for the case of GAS. Second, the ECT is statistically significant where it is bear by gas energy consumption in the case of GAS. Third, speed of adjustment stands at 84.49 per cent per year in case of GAS due to the short run adjustment. So, this implies that Malaysia will need 1.18 years to adjust back to long run equilibrium. So, gas energy consumption functions as the initial receptor of any exogenous shocks that distort the equilibrium system in Malaysian industry sector. Fourth, the ECT result shows the existence of long run causality running from Y, CO2 emissions and EMP to gas energy consumption.

Next, results for VAR causality system were portrays in Table 3 for which cointegration is absence. The results clearly show that the existence of short run unidirectional causality relationship running from EMP to EC for all aggregate, COAL and OIL. Bidirectional causality short run relationship exists between Y and EC for the case of aggregate, and between coal

EC and CO2 emissions for the case of COAL. In addition, short run unidirectional causality were detected from Y to CO2 emissions for the case of aggregate and COAL; from Y to EC for the case of COAL and OIL; EMP to CO2 emissions for the case of aggregate (refer to Figure 1).

Table 2
Vector Error Correction Model Granger Causality Tests for Gas

Case	Dependent Variables	χ^2-statistic (p-value)				ECT	
		ΔLY	ΔLEC(gas)	ΔLCO2(gas)	ΔLEMP	Coefficient	T-Statistic
GAS	ΔLY	-	2.6372(0.1044)	0.4786(0.4891)	0.0792(0.7784)	-0.0092	-0.8687
	ΔLEC(gas)	0.1299(0.7185)	-	3.2265(0.0725)	3.6617(0.0557)	-0.8449**	-20.9981
	ΔLCO2(gas)	0.6835(0.4084)	1.6782(0.1952)	-	0.7071(0.4004)	-0.0913	-0.8541
	ΔLEMP	0.0229(0.8798)	0.4019(0.5261)	0.0147(0.9036)	-	0.0006	0.1468

Notes: "Δ" is the first different operator. Asterisks (**) indicates statistically significant at 5 percent level.

Table 3
Granger Causality Test in VAR Results

Case	Dependent Variables	χ2-statistic (p-value)			
Aggregate		ΔLY	ΔLEC	ΔLCO2	ΔLEMP
	ΔLY	-	4.1213**(0.0423)	3.1525(0.0758)	0.1790(0.6722)
	ΔLEC	6.5237**(0.0106)	-	2.7386(0.0979)	7.3424**(0.0067)
	ΔLCO2	5.9464**(0.0147)	2.5946(0.1072)	-	11.2390**(0.0008)
	ΔLEMP	0.0088(0.9253)	0.0133(0.9081)	0.0180(0.8932)	-
COAL		ΔLY	ΔLEC(C)	ΔLCO2(C)	ΔLEMP
	ΔLY	-	1.4024(0.2363)	1.7935(0.1805)	0.0244(0.8759)
	ΔLEC(C)	22.8651**(0.0000)	-	19.3582**(0.0000)	8.0399**(0.0046)
	ΔLCO2(C)	8.1475**(0.0043)	19.4546**(0.0000)	-	1.3420(0.2467)
	ΔLEMP	0.0098(0.9212)	0.4390(0.5076)	1.3768(0.2406)	-
OIL		ΔLY	ΔLEC(oil)	ΔLCO2(oil)	ΔLEMP
	ΔLY	-	0.7710(0.3799)	0.3795(0.5379)	1.7260(0.1889)
	ΔLEC(oil)	10.6205**(0.0011)	-	2.5956(0.1072)	16.3429**(0.0001)
	ΔLCO2(oil)	0.0156(0.9005)	1.8350(0.1755)	-	1.5344(0.2154)
	ΔLEMP	0.1084(0.7420)	0.2741(0.6006)	0.1359(0.7124)	-

Notes: "Δ" is the first different operator. Asterisks (**) indicates statistically significant at 5 percent level.

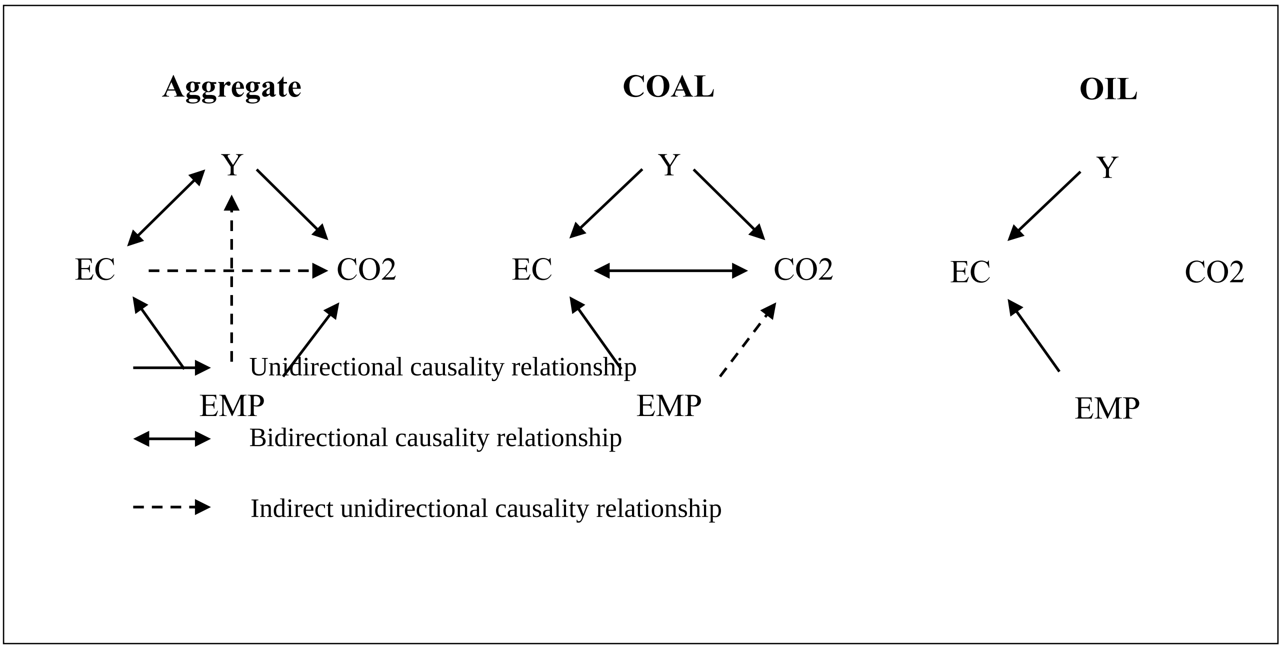

Figure 1: Short Run Granger Causality Test

Concluding Remarks

This study explores the causal relationships between real income (Y), energy consumption (both aggregate and disaggregate), CO2 emissions (both aggregate and disaggregate), and employment in Malaysia's industrial sector. Using the time-series econometric techniques, this study discovered unidirectional causality between Y, CO2 emissions, and employment to gas energy consumption over the long run. The results imply that higher employment and economic growth are associated with increased gas resource consumption.

In the short run, the study identified causality from (*i*) employment to energy consumption for coal, oil, and all aggregates; (*ii*) Y to CO2 emissions for coal and aggregates; (*iii*) Y to energy consumption for coal and oil; and (*iv*) employment to CO2 emissions for aggregates. Furthermore, there is a bidirectional short run causal relationship between Y and aggregate energy consumption as well as between coal energy consumption and CO2 emissions.

Undoubtedly, Malaysia's rapid industrialization would lead to a rise in energy consumption, which is necessary for the country to reach full industrialization (Tan and Tan, 2018). Fossil fuels, such as coal, oil, and natural gas, are frequently utilized to generate energy in Malaysia, and employment still plays a crucial role in the Malaysian industrial sector. The circumstances in Malaysia are similar to those in many other emerging nations. Therefore, in order to protect the environment for future generations without negatively impacting the economy, the Malaysian government should develop regulations to minimize the use of fossil fuels and environmental degradation. For instance, funding green energy initiatives is advised, with a special emphasis on hydropower, solar and other renewable energies. Prioritizing ongoing research, development, and innovation is important as diversify energy resources beyond fossil fuels, which the fossil fuels will eventually be depleted. It is sense to investigate the possibility for electrification using hydropower, solar and other renewable energies to replace the fossil fuels in Malaysia. But caution should be exercised in light of the societal ramifications of such ambitious economic initiatives (Lau et al., 2016).

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