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Will economic sophistication contribute to Indonesia's emission target? A decomposed analysis

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ABSTRACT

Indonesia aspires to reduce 29%–41% of the nation's carbon emissions by 2030 and to reach net zero-carbon emissions by 2060. The production paradigm of the Indonesian economy still relies entirely on dirty energy sources, including coal, oil and gas. As it is a natural resource-abundant developing country, we simulate the decomposed carbon emissions response to mounting economic growth and the Economic Complexity Index (ECI) for the next 20 years, applying a dynamic simulated autoregressive distributed lag approach using time series data from 1966 to 2018. Our investigation demonstrates that economic growth and increased ECI help to reduce carbon emissions–oil use intensity and vice versa. Conversely, gas and coal emissions intensities respond positively to ECI, but negatively to economic growth. Our findings confirm that inadequate technological improvement in gas and coal use-oriented industries are detrimental to decoupling the economic growth–emissions relationship.

1. Introduction

Indonesia has enjoyed robust economic growth at the expense of significant environmental degradation. The economy is anticipated to become the fifth-largest in the world by 2030, with an expected GDP of USD 5.42 trillion (Pricewaterhouse Coopers, 2017). Simultaneously, the Indonesian government has committed to the United Nations Framework Convention on Climate Change to reduce 29%–41% of the nation's carbon emissions by 2030 and to achieve net zero-carbon emissions by 2060. A recent analysis argues that the country must invest approximately USD 200 billion/year in mitigation programmes to meet its carbon emissions target over the next nine consecutive fiscal years (Reuters, 2021). Indonesia has adopted a few policy measures, including energy efficiency, promoting clean energy share, less carbon fuel switching and the adoption of green technology in the energy industry (Fragkos et al., 2021). To achieve the low-carbon energy targets of the Paris Agreement, electricity and transportation in Indonesia are two prioritised sectors in which to conduct the carbon intensity (CI) reduction process. Regarding Indonesia's current reality and development, the projection of advancing the renewable energy mix in primary energy consumption and power generation may not corroborate the target of the General National Energy Plan (RUEN). The nation aspires to ensure the inclusion of a 23% proportion of renewable energy in the total energy mix by 2050. The projection of fossil energy mix also mismatches the RUEN target, indicating that policymakers must review the plan for 2015–2050 RUEN. In addition, Indonesia enjoys a significant volume of trade earnings, primarily through exporting natural resources and foreign remittance inflow. Given the nation's export-oriented economy, coupled with its labour abundance, we are motivated to investigate the dynamic impact of Indonesia's Economic Complexity Index (ECI) on various measures of CI, including oil, gas and coal.

Indonesia may encounter some challenges in achieving carbon emissions targets for three primary reasons. First, the COVID-19 pandemic led to a national economic recession, as around 1.8 million people lost their jobs and 2.8 million people fell below the poverty line. To tackle these circumstances, Indonesian fiscal policy might focus on economic recovery rather than green investment. Second, the nation's economic growth still relies on sectors that primarily use dirty energy; for instance, Indonesian foreign earnings depend heavily on coal extraction and exports, crude oil and palm oil. Third, Indonesia is

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following the traditional economic growth paradigm, which could be counterproductive to achieving carbon emissions targets. Subsequently, the country must advance the adoption of a knowledge-based economy to enjoy robust economic growth while minimising negative externalities.

Many developed countries have curbed carbon emissions through technological progress (Zhao et al., 2021; Sohag et al., 2019a, 2019b; Samargandi, 2017). The literature argues that economic structural change paving the way to a knowledge-based production process is imperative for promoting energy efficiency and ultimately reducing carbon emissions (Balsalobre-Lorente et al., 2021; Can and Gozgor, 2017). To examine these effects, we simulate the impact of the ECI on emissions intensities in the context of Indonesia. Hidalgo and Hausmann (2009) propose the ECI for determining the intensity of technological knowledge use in producing a wide range of products targeting domestic and international consumers. Simoes and Hidalgo (2011) argues that the production process requires capabilities along with labour and capital. Research attributes these capabilities as non-saleable goods and services, including infrastructure development, intellectual property rights, policies and skilled labour (Hidalgo and Hausmann, 2009). Some recent articles conclude that the ECI is useful for explaining countries' carbon emissions function, e.g. Doğan et al. (2021) for developed countries; Neagu (2019) for European Union countries; Qayyum et al. (2021) for cross-countries; and Leitão et al. (2021) for the BRIC countries, Brazil, Russian, India and China. Accordingly, we argue that the ECI can reflect the degrees of knowledge, skilled labour and sophisticated production of Indonesia over time, with significant implications for various carbon emissions intensities. Subsequently, we believe that the Indonesian economy requires economic sophistication and knowledge accumulation in the working population to advance efficiency, emissions decoupling and the reduction of CI from the total energy mix. This study endeavours to simulate the impact of economic sophistication on decomposed CI for the next ten years using the ECI.

The primary contributions of this study are threefold. First, our study generates decomposed emissions intensities from oil, natural gas and coal usages over time. Second, it represents the first attempt to simulate the impact of the ECI on decomposed emissions intensities exclusively for the Indonesian economy, where primary sector emissions intensity has a pivotal role in economic growth. Third, using a dynamic simulated autoregressive distributed lag (DSARDL) approach, our simulation reveals several new insights, demonstrating that augmentation of economic complexity helps reduce oil emissions intensity, whereas it has an insignificant role in influencing coal and gas emissions intensities. Our findings offer several practical policy implications.

The remainder of this paper is organised as follows. Section 2 discusses prior studies on the subject. Section 3 details our methodology and data. Section 4 presents the results and discussion. Section 5 is the conclusion of the paper and our recommendations.

2. Review of literature

Recent studies scrutinise the influence of the ECI on carbon emissions for various countries, e.g. Doğan et al. (2021) for developed countries; Neagu (2019) for European Union countries; Qayyum et al. (2021) for cross-countries; and Leitão et al. (2021) for BRIC. Previous studies demonstrate a positive correlation between CI and economic growth (Malzi et al., 2020; de Mendonça and Tiberto, 2017; Begum et al., 2015a, 2015b), indicating that higher GDP growth is correlated with higher carbon emissions. Wang and Wang (2020) find a positive correlation between carbon emissions and economic performance. China's industrial CI decreased overall, which had an influence on reducing the nation's national CI. Grossman and Krueger (1995) explain that the initial phase of economic growth is accompanied by a commensurate phase of environmental degradation, which reduces with continued economic growth and eventually begins to dissipate. Several studies highlight the correlation between energy use and environmental degradation (e.g. Dong et al., 2022; Balsalobre-Lorente et al., 2018; Taghizadeh-Hesary et al., 2021; Sharma et al., 2021).

Elheddad et al. (2021) consider several control variables, including fossil and non-fossil energy consumption, urbanisation and manufacturing production to examine the Environmental Kuznets Curve (EKC) for countries in the Organisation for Economic Cooperation and Development (OECD) with data from 2007 to 2016. The study concludes that e-finance can reduce carbon dioxide (CO_2) emissions in OECD countries and significantly reduce carbon emissions. Sinha et al. (2020) in their study on EKC related to the United Nations' Sustainable Development Goals, validate the EKC hypothesis. Sinha et al. (2020) and Du et al. (2019) use economic data from 1996 to 2012 to examine the effect of green technology innovation on CO_2 emissions, demonstrating that income levels have an important influence on green technology innovation. They also observe that green technology innovation has a threshold effect on income level and the mitigating effect has a significant impact on those with income levels exceeding the threshold. The study results indicate that innovation mechanisms should be implemented to reduce the costs of green technology diffusion in countries with underdeveloped economies. Another related investigation by (Chen et al., 2021) reveals that technological innovation positively impacts energy efficiency performance and economic growth negatively influences energy efficiency.

Furthermore, strategic economic structural change has a positive impact on energy efficiency. Ali et al. (2021) find that production expenditure on clean technology innovation can simultaneously increase GDP and improve environmental conditions in the case of G7 countries. Hao et al. (2021) support other research emissions-related by comparing the proportion of labour force to emissions levels, demonstrating that the higher the labour force ratio in the non-agricultural sector, the higher the emissions produced, which is also influenced by the movement of labour between industrial and non-industrial sectors. Tateishi et al. (2020) evaluate the role of various institutions based on the concept of transaction costs in GDP efficiency and greenhouse gas (GHG) mitigation efficiency, which allows the new institutional economics to have an empirical assessment of inefficiency in production. Their research results show that no institutions improve environmental efficiency or technological efficiency; emission reductions generate economic output. Furthermore, for countries with extremely high institutional quality, environmental efficiency and technological efficiency approach the efficient margin and exhibit higher fluctuations in fossil energy inputs at the environmental efficiency threshold.

Countries with low institutional quality can exploit some gaps to improve environmental and technological efficiency by raising the quality of institutions. Through a decomposition of the Malmquist index, Song et al. (2020) demonstrate that increases in research collaboration related to overall industry–university innovation efficiency in China has an impact on technological progress, which is the main driving factor for advancing the decline in CI. According to the regression model results, CI in China indicates that increasing industrial and university research collaboration can indirectly reduce carbon emissions. Ma et al. (2020) argue that if China does not take adequate measures to reduce emissions, it will face serious environmental challenges in the next decade. Furthermore, green innovation has a considerable influence by encouraging capacity building for green innovation, which researchers demonstrate to reduce carbon emissions effectively. Zhang et al. (2020) reveal a significant and positive autocorrelation and heterogeneity of CI values between cities, indicating that technological changes and increased environmental efficiency are the primary factors behind CI changes. Technological advances have an essential role in reducing the CI value, while the rebound effect of carbon emissions can reduce this positive impact. The researchers also reveal that an insignificant effect of industrial structure optimisation and technological progress in reducing CI. The study recommends specific strategic governmental policies aimed at reducing CI, including promoting green technology at regional levels through collaboration with other green innovative cities.

The research can help local governments formulate urban development strategies and strengthen inter-city cooperation.

Economic growth based on fossil fuels generates significant environmental pressure, such as CO_2 emissions resulting from production and consumption. Lin and Chang (2015) examine the interrelationships between energy use and environmental quality, comparing Germany, Japan and the United States. Emissions data are sourced from five components of pollution coefficients, fuel mixture, energy intensity, economic growth and industrial structure. The most significant positive effect on emissions changes is correlated with economic growth. Sulphur dioxide (SO_2) emissions in industry and other sectors have a downward trend due to improved fuel quality and pollution control; however, nitrogen oxides (NO_x) and CO_2 emissions have a high increase. This demonstrates that energy efficiency improvement, pollution control and fuel substitution are the main options for saving SO_2, NO_x and CO_2. However, not all industrial sectors have the same impact as emissions sources (Li et al., 2021) identify the chemical, metallurgical, electricity and hot water sectors as the primary transmission sectors. This research was conducted in China and proves that the first three production layers account for 95% of CO_2 emissions. In contrast, the production efficiency policy in each sector, both downstream and upstream in the supply chain, has a significant impact on reducing CO_2 emissions. Considering adjacent geographical positions when transporting raw materials from upstream to downstream industries can also reduce carbon emissions from the transportation industry.

Regarding international trade supply chains, Tulpulé et al. (1999), Shapiro (2020) and Zhong et al. (2021) quantify trade models and environmental impacts, investigating the impact of CO_2 emissions from shipping. The results indicate that the benefits of international trade outweigh the environmental costs of CO_2 emissions. A proposed regional carbon tax on CO_2 emissions from shipping would increase global welfare, raise the GDP of implementing regions and harm developing countries involved in international trade. However, by investigating the potential costs, risks and returns on investment, developed countries can reduce the impact of trade emissions by establishing emission reduction projects in developing countries (Gundimeda and Guo, 2003).

According to a 2020 brief on Indonesia from the Massachusetts Institute of Technology's Observatory of Economic Complexity (OEC), the nation ranks 16th in the global economy in terms of GDP (current USD), 30th in total exports and total imports, 68th as the most complex economy according to the ECI and 117th in economic GDP per capita (current USD). Indonesia is a major exporter of coal briquettes, palm oil and fuel oil, and its exports are primarily to China, the United States and Japan. Indonesia was also the world's largest exporter of palm oil, lignite and stearic acid, and its three main imports were refined petroleum, crude oil and vehicle parts, which were primarily imported from China, Singapore and Japan. Reviewing Indonesia's general economic profile, several traded commodities are categorised as having a significant impact on the environment and climate change; however, the nation has made substantial progress in energy and security in the last decade, in terms of both access and reliability. The Indonesian government is optimistic about fulfilling its commitment to the energy transition in response to technological shocks to adapt to climate change under the Paris Agreement, by taking bold measures towards an environmentally sustainable energy system, particularly by reducing the CI of energy supply, which has increased substantially over the past decade. The energy system is essential for Indonesia's economic growth, as a source of export revenue, significant employment and competitiveness. As the largest energy consumer in Southeast Asia and a source of rising demand, Indonesia is critical to effective CI reduction. A robust and strategic enabling environment for CI reduction, characterised by increased political commitment to energy transition, mechanisms to attract capital and investment and just transition pathways to ensure equitable distribution of costs and benefits from CI reduction are critical for accelerated progress in Indonesia.

The OEC profile indicates that coal, oil and natural gas are Indonesia's primary trading commodities. Previous studies related to gas, oil and coal emissions have negative and significant interactions for fossil energy and GDP. One study demonstrates that non-renewable energy coupled with technological inefficiency has a detrimental impact on economic growth (Malzi et al., 2020). Changes from fossil to non-fossil energy use, if implemented in the short term, can impact oil, gas and coal price shocks because this transition necessitates the preparedness for funding related infrastructure for an operational system, which requires a considerable amount of time. As noted by (Amiri et al., 2021), oil price shocks, coupled with rising oil revenue, result in the expansion of the monetary base and ultimately lead to higher liquidity growth and inflation. The same is true for non-fossil energy commodities. In addition, such energy price shocks lead to a depreciation in the real exchange rate and a decline in economic competitiveness.

Our thorough review of previous literature identified no comprehensive study highlighting the role of economic complexity in reducing decomposed measures of CI. Our study aims to fill this research gap.

3. Methodology

3.1. Data and sources

We generate three development variables in this study, including carbon emissions–oil use intensity, carbon emissions–gas use intensity and carbon emissions–coal use intensity. Our main independent variables are GDP per capita, a square form of GDP per capita and the ECI (Fig. 1). We use annual time-series data from 1966 to 2019 taken from the World Development Indicators database (World Bank, 2021), the BP Statistical Review of World Energy and Our World in Data, 2021 (Table 1).

Prior to estimating our model, we perform a unit root test to identify our variables' order of integration, applying augmented Dickey–Fuller (ADF) and Phillips–Perron (PP).

3.2. Autoregressive distributed lag (ARDL) model

We estimate our models by applying the standard ARDL model bounds testing approach, suggested by Pesaran et al. (2001a, b). The ARDL model has different advantages than other time series models to avoid ‘spurious regression’ problems in time series, as different lags can be used for regressand and regressor variables. The estimated results of the ARDL bounds test indicate that cointegration exists among the study variables.

$$\begin{aligned}\Delta EMOIL_t = {} & \alpha + \beta_1 EMOIL_{t-1} + \beta_2 ECI_{t-1} + \beta_3 LGD\mathrm{PC}_{t-1} + \beta_4 LGDPC^2_{t-1} \\ & + \sum_{i=1}^{p} \nu_1 \Delta EMOIL_{t-i} + \sum_{i=0}^{q} \nu_2 \Delta ECI_{t-1} + \sum_{i=0}^{q} \nu_3 \Delta LGDPC_{t-1} \\ & + \sum_{i=0}^{q} \nu_4 \Delta LGDPC^2_{t-1} + \varepsilon_t \end{aligned} \tag{1}$$

$$\begin{aligned}\Delta EMGAS_t = {} & \alpha + \beta_1 EMOIL_{t-1} + \beta_2 ECI_{t-1} + \beta_3 LGDPC_{t-1} + \beta_4 LGDPC^2_{t-1} \\ & + \sum_{i=1}^{p} \nu_1 \Delta EMOIL_{t-i} + \sum_{i=0}^{q} \nu_2 \Delta ECI_{t-1} + \sum_{i=0}^{q} \nu_3 \Delta LGDPC_{t-1} \\ & + \sum_{i=0}^{q} \nu_4 \Delta LGDPC^2_{t-1} + \varepsilon_t \end{aligned} \tag{2}$$

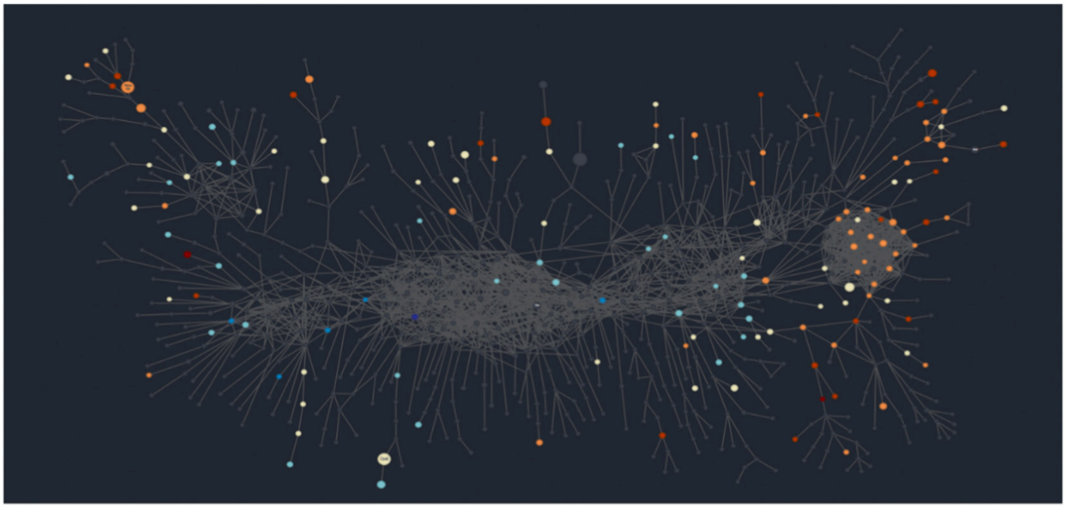


Fig. 1. Economic Complexity Index visualisation for Indonesia.

Table 1
Description of variables and sources.

Variable	Description	Unit	Source
Emissions–Oil Intensity (EMOIL)	EMOIL indicates tonnes of carbon emissions per TWh of oil use.	Emissions tonnes/oil use TWh	BP Statistical Review of World Energy, 2021
Emissions–Gas Intensity (EMGas)	EMGAS indicates tonnes of carbon emissions per TWh of gas use.	Emissions tonnes/gas use TWh	BP Statistical Review of World Energy, 2021
Emissions–Coal Intensity (EMCoal)	EMCOAL indicates tonnes of carbon emissions per TWh of coal use.	Emissions tonnes/coal use TWh	BP Statistical Review of World Energy, 2021
GDP per capita (LGDPC) in log form	As a proxy of real economic growth, the value of the output of a certain period based on the basic or constant price in an economy.	Ratio of nominal GDP is divided by GDP deflator (R)	World Bank, 2021
Economic Complexity Index (ECI)	The ECI measures the relative knowledge intensity of an economy. The higher the index, the more economically complex a country is determined to be.	Index	Our World in Data, 2021

$$\Delta EMCOAL_t = \alpha + \beta_1 EMOIL_{t-1} + \beta_2 ECI_{t-1} + \beta_3 LGDPC_{t-1} + \beta_4 LGDPC^2_{t-1} + \sum_{i=1}^{p} \nu_1 \Delta EMOIL_{t-i} + \sum_{i=0}^{q} \nu_2 \Delta ECI_{t-1} + \sum_{i=0}^{q} \nu_3 \Delta LGDPC_{t-1} + \sum_{i=0}^{q} \nu_4 \Delta LGDPC^2_{t-1} + \varepsilon_t \tag{3}$$

Eqs. 1, 2 and 3 reveal the first difference, technological shock and emissions per capita. EMOIL represents oil emissions, EMCOAL indicates coal emissions and EMGAS represents gas emissions. β shows the lag dependent and independent parameters. The ν vector indicates the short-run parameters. To examine the cointegration relations, the following hypothesis must be estimated via Wald test.

$$H_0 : \beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$$

$$H_a : \beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq 0$$

We can use the result of the F-statistics value to reject the null hypothesis. If the calculated F-statistics values are more significant than the upper bound value, this indicates the long-run association between the study variables and vice versa (Pesaran et al., 2001a, b). Finally, we estimate long- and short-run equations, including the error correction term.

3.3. Dynamic simulated autoregressive distributed lag (DSARDL)

To simulate our three empirical models, we apply the DSARDL technique to remove the complications of the existing ARDL for investigating both the short-run and the long-run associations among the study variables. The DSARDL method is efficient for predicting, simulating and forecasting the actual change in independent variables and affecting the dependent variables, assuming the remaining variables in the equation are constant. This method can also solve the endogeneity problem, which can lead to spurious regression. To use the dynamic simulation ARDL method, we must ensure that the dependent variable is I(1), the regressors are not of an order of integration and the analysis estimates an ARDL model in error-correction form (Jordan and Philips, 2018a, b).

$$logEMOIL_t = \alpha + \beta_1 EMOIL_{t-1} + \beta_2 ECI_{t-1} + \beta_3 LGDPC_{t-1} + \beta_4 LGDPC^2_{t-1} + \varepsilon_t \tag{4}$$

$$logEMGAS_t = \alpha + \beta_1 EMOIL_{t-1} + \beta_2 ECI_{t-1} + \beta_3 LGDPC_{t-1} + \beta_4 LGDPC^2_{t-1} + \varepsilon_t \tag{5}$$

$$logEMCOAL_t = \alpha + \beta_1 EMOIL_{t-1} + \beta_2 ECI_{t-1} + \beta_3 LGDPC_{t-1} + \beta_4 LGDPC^2_{t-1} + \varepsilon_t \tag{6}$$

Table 2
Descriptive statistics.

Variable	Obs	Mean	Std dev	Min	Max
EMOIL	54	12.488	0.170	12.104	12.849
EMGAS	54	12.253	0.469	11.487	13.974
EMCOAL	54	12.713	0.327	11.692	13.315
ECI	54	−0.715	0.613	−1.823	−0.006
LGDPC	54	3.247	0.236	2.809	3.6484

Source: Author calculation.

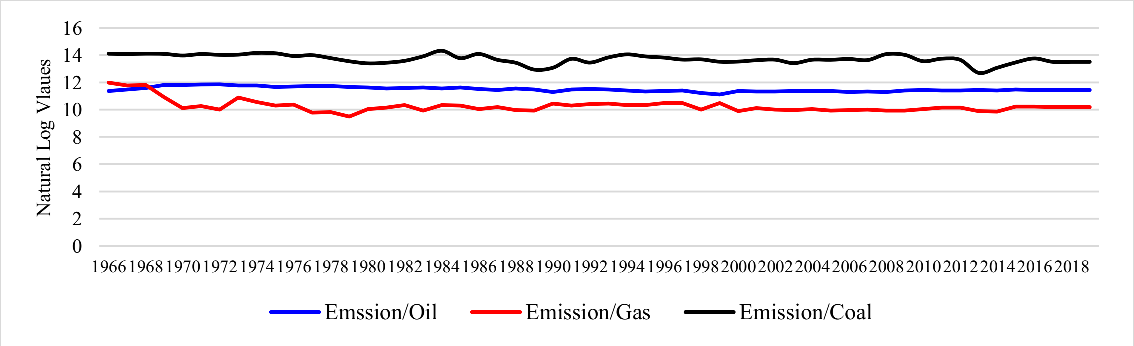


Fig. 2. Decomposed carbon emissions intensities 1966–2018.

4. Results and discussion

4.1. Descriptive statistics result

Table 2 presents a summary of the descriptive statistics of our respective variables in natural logarithmic forms. The mean values of EMOIL, EMGAS and EMCOAL marginally vary from one another. The table also shows that EMOIL has a minimum standard deviation. Our analysis indicates that variation in the ECI is highest over time compared with other variables.

4.2. Emissions intensities and economic complexity under standard ARDL

The energy sector sets a GHG emissions reduction target of 314 million tonnes, or the equivalent of 11%, under scenario conditions excluding unconditional reduction requirements. Indonesia aspires to achieve this emissions reduction goal by implementing sector-based mitigation measures. Fig. 2 demonstrates the decomposed CI from 1966 to 2019. The CI of natural gas use dropped in 1970, remaining constant over time. Coal intensity remains highest in comparison to oil and gas intensities. Fig. 2 also indicates that gas intensity is lower, reflecting natural gas as a transitional energy. The carbon emissions intensity of oil use is between that of coal and oil use.

Tables 3a and 3b summarise our results regarding the order of integration of our respective variables. The table clearly shows that our variables follow a mixed integration order under ADF and PP approaches. ADF has certain advantages in terms of managing serial correlation by adding autoregressive terms with sufficient lag orders, while the PP approach is efficient for managing the non-normal properties of the data due to the non-parametric attributes. Non-stationarity and the mixed order of integration indicate the validity of using the standard ARDL bounds testing approach and DSARDL to estimate our three empirical models.

Table 4 presents the results of our three empirical models obtained from the standard ARDL techniques. Regarding Model 1, the coefficient of the error correction mechanism is negative and significant, implying that oil emissions intensity, economic growth and ECI converge towards the long-run equilibrium. Table 4 demonstrates that Model 1 adjusts 68% per year towards the long-run equilibrium after any exogenous shock. The coefficient of GDP is negative, whereas the coefficient of the quadratic form of GDP is positive and significant, indicating that emissions–oil intensity and economic growth follow a U-shaped relationship. Our results imply a contradiction of the EKC hypothesis, consistent with prior studies (e.g. Begum et al., 2015a, b; Sohag et al., 2019a, b). The most striking finding is that the long-run coefficient of the ECI is negative and significant, implying that an increase of ECI helps to reduce emissions–oil intensity. These findings partially with previous research demonstrating that ECI reduces carbon emissions (Qayyum et al., 2021; Doğan et al., 2021; Leitão et al., 2021; Neagu, 2019).

Regarding Model 2, with gas emissions intensity as the dependent variable, we find 38% adjustment rates towards the long-run equilibrium, which is lower than Model 1. The coefficient of GDP is positive, whereas the coefficient of the square form of GDP is negative and significant, indicating that the emissions–gas intensity and economic growth follow an inverted U-shaped relationship. Our findings partially echo previous studies confirming the EKC for several developing and developed countries (Sohag et al., 2021; Shahbaz et al., 2020a, b; Zheng et al., 2019). Our finding can be explained by the fact that Indonesia has significant reserve of natural gas, which is a transitional energy. The nation extracts approximately twice as much natural gas as it uses;

Table 3a
Order of integration.

Unit root test results table (ADF)					
At level					
	ECI	EMCOAL	EMGAS	EMOIL	LGDPC
With constant	−0.7319	−3.4965**	−4.4321***	−1.3248	−0.9082
With constant & trend	−1.2996	−4.0482**	−4.2119***	−2.3463	−2.5858
Without constant & trend	−1.3710	−0.3716	−1.0299	−0.2338	8.5307
At first difference					
	ΔECI	ΔEMCOAL	ΔEMGAS	ΔEMOIL	ΔLGDPC
With Constant	−6.7694***	−6.8102***	−9.0735***	−6.5150***	−5.3876***
With Constant & Trend	−6.7015***	−6.7290***	−9.3290***	−6.4325***	−5.3621***
Without Constant & Trend	−6.7464***	−8.5360***	−9.5313**	−7.4691***	−2.8084*

*** Indicates 1% significance level.
** Indicate 5% significance level.
* Indicate 10% significance level.

Table 3b
Order of integration.

Unit root test results table (PP)

	ECI	EMCOAL	EMGAS	EMOIL	LGDPC
With constant	−0.7683	−3.5208	−5.0371***	−1.9041	−0.8566
With constant & trend	−1.4018	−4.0482	−4.3583**	−3.4552*	−2.2731
Without constant & trend	−1.3452	−0.4842	−1.0545	0.0959	7.3160

At first difference

	ΔECI	ΔEMCOAL	ΔEMGAS	ΔEMOIL	ΔLGDPC
With constant	−6.7748***	−8.4697***	−9.0751	−7.9185***	−5.3540***
With constant & trend	−6.7075	−8.3821	−9.9195	−7.7858	−5.3276
Without constant & trend	−6.7164	−8.5360	−9.0313	−7.9691	−2.9084*

*** Indicates 1% significance level.
** Indicate 5% significance level.
* Indicates 10% significance level.

Table 4
Dynamic impact of technology on decomposed emissions intensity.

Regressor	Emissions–oil intensity (M1)	Emissions–gas intensity (M2)	Emissions–coal intensity (M3)
Long-run coefficients			
$LGDPC_{t-1}$	−8.9457***	7.2446***	8.6534***
	(1.8670)	(1.0915)	(0.7650)
$LGDPC^2_{t-1}$	1.3212***	−1.0808***	−1.4502***
	(0.2825)	(0.3130)	(0.2191)
ECI_{t-1}	−0.1037***	−0.0681	0.0500
	(0.0450)	(0.3158)	(0.2484)
Short-run coefficients			
$\Delta LGDPC$	−6.1061***	2.7744***	3.7394***
	(1.3273)	(0.9778)	(1.0498)
$\Delta LGDPC^2$	1.1132***	−0.41392**	−0.6266***
	(0.2176)	(0.1935)	(0.1898)
ΔECI	−0.0708***	−0.0261	0.0216
	(0.0376)	(0.1191)	(0.1069)
ECM_{t-1}	−0.6825***	−0.3829***	−0.4321***
	(0.1184)	(0.0981)	(0.1175)
N	58	58	58

*** Indicates 1% significance level.
** Indicates 5% significance level.
* Indicates 10% significance level.

however, the extracted amount fails to meet domestic demand. The Indonesian government-owned gas company, Perusahaan Gas Negara cannot satisfy domestic demand. The coefficient of ECI is negative but insignificant, implying that ECI helps to reduce gas emissions intensity overall.

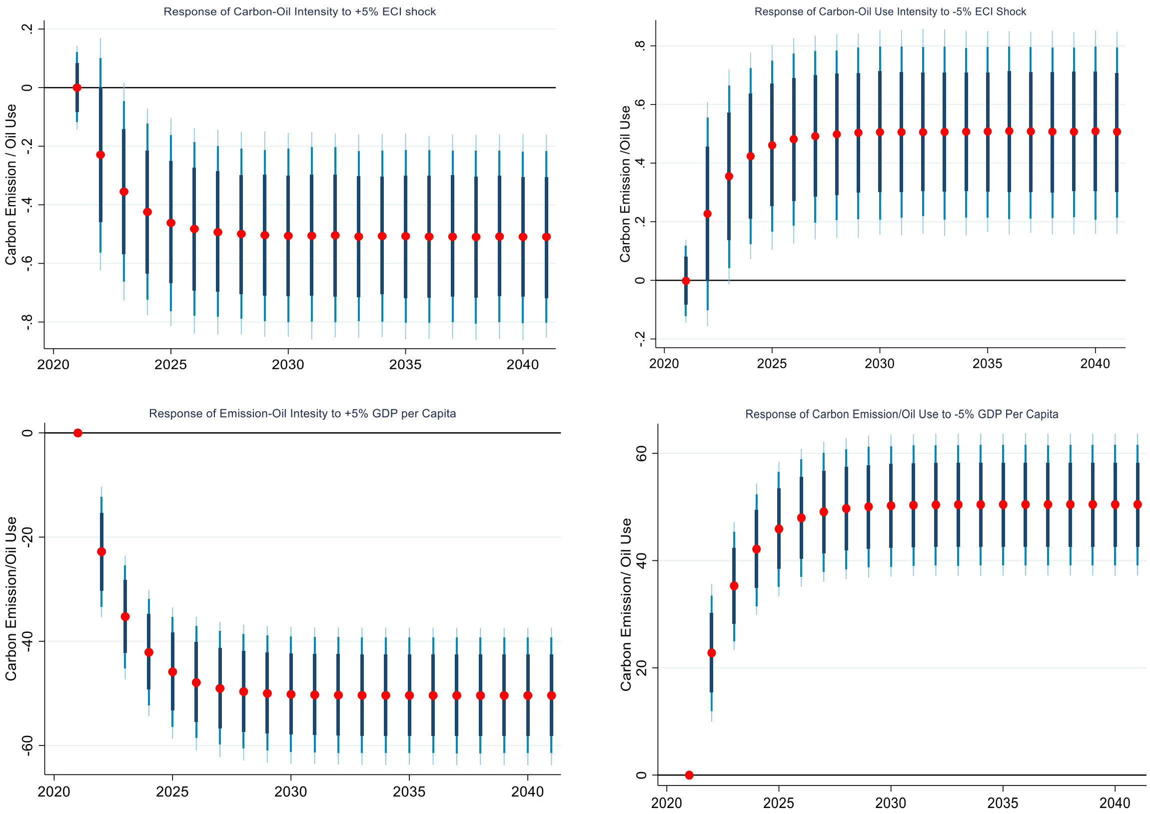
Model 3 presents the dynamic impact of economic growth and ECI on coal emissions intensity. The coefficient of ECI is 43% for coal emissions intensity. The convergence rate for emission coal intensity is between the emissions intensities of oil and gas. Model 3 adjusts 43% per year towards the long-run equilibrium after any exogenous shocks. The coefficient of GDP is positive, while the coefficient of the square form of GDP is negative and significant, indicating that emissions–coal intensity and economic growth follow an inverted U-shaped relationship supporting the EKC hypothesis; however, the coefficient of ECI appears to be positive and insignificant. Indonesia has been a leading coal exporter and user since 2000. It appears that growing economic sophistication failed to replace coal energy with cleaner energy in Indonesia due to short-run economic gain.

4.3. *Emission intensities and economic complexity under DSARDL*

We next present the response of emissions intensities to the ECI using the DSARDL approach. Fig. 3 presents the response of emissions–oil use intensity to 5% positive shocks in the ECI for 2020–2040, revealing that the response curve sharply moves down towards the positive shocks of the ECI. Since the response curve and confidence interval are below the zero line, a positive shock in economic complexity appears to lead to reduced emissions–oil intensity, consistent with the standard ARDL approach. The response of emissions–oil intensity to a 5% negative shock in the ECI is the mirror version of the positive shock. Emissions–oil intensity also responds negatively towards a positive shock in 5% economic growth. The magnitude of response to GDP growth is higher than the response to the ECI. As an emerging country, Indonesia is moving towards the nature of developed countries to encounter the EKC.

According to Shahbaz et al. (2020a, b), who examined CO_2 and its determinants, financial development and research and development (R&D) are the keys to environmental protection at industrial age 4.0. R&D may be a solution for reducing environmental pollution, as the intensity of carbon emissions from the adjustment of the industrial structure in China from poverty alleviation across the country presents a general downward trend due to supply-side reforms, environmental regulations and industrial restructuring (Fu et al., 2021). The problem of gas, oil and coal emissions is a general industrial dilemma; however, the question remains regarding who is most responsible: the upstream industry or the downstream industry? Investigations of the environmental impact of upstream and downstream industries are conducted by Li et al. (2021) and Hu et al. (2021), arguing that encouraging transmission centres to increase efficiency can reduce CO_2 emissions in upstream supply chains. The researchers consider companies to be the main transmission centres, and high efficiency refers to fewer intermediary inputs and lower costs, which enterprises will welcome. One of the emissions reduction policies in Indonesia is energy conservation, which is conducted by raising energy use efficiency from upstream to downstream, considering that it has an even impact on emissions in Indonesia (Minister of Environment Life and Forestry Indonesia, 2021). The critical factors for maintaining economic growth under emissions reduction targets are consumption and investment and how policymakers strategically respond to the above results. At the same time, Indonesia also can advance the use of renewable energy to reduce carbon emissions. Transitional opportunities include geothermal power, solar power, small-scale hydroelectric power and biomass, all of which are compatible with the Paris Agreement target (Minister of Environment Life and Forestry Indonesia, 2021).

Fig. 4 presents the response of emissions–gas use intensity to the ECI, which is positive and significant, implying that economic complexity growth may not reduce the emissions–gas use intensity. Nevertheless, gas use intensity responds negatively to a 5% increase in GDP per capita. Our result can be explained by the fact that the technology in gas use industries remains constant, whereas the technology in oil-oriented

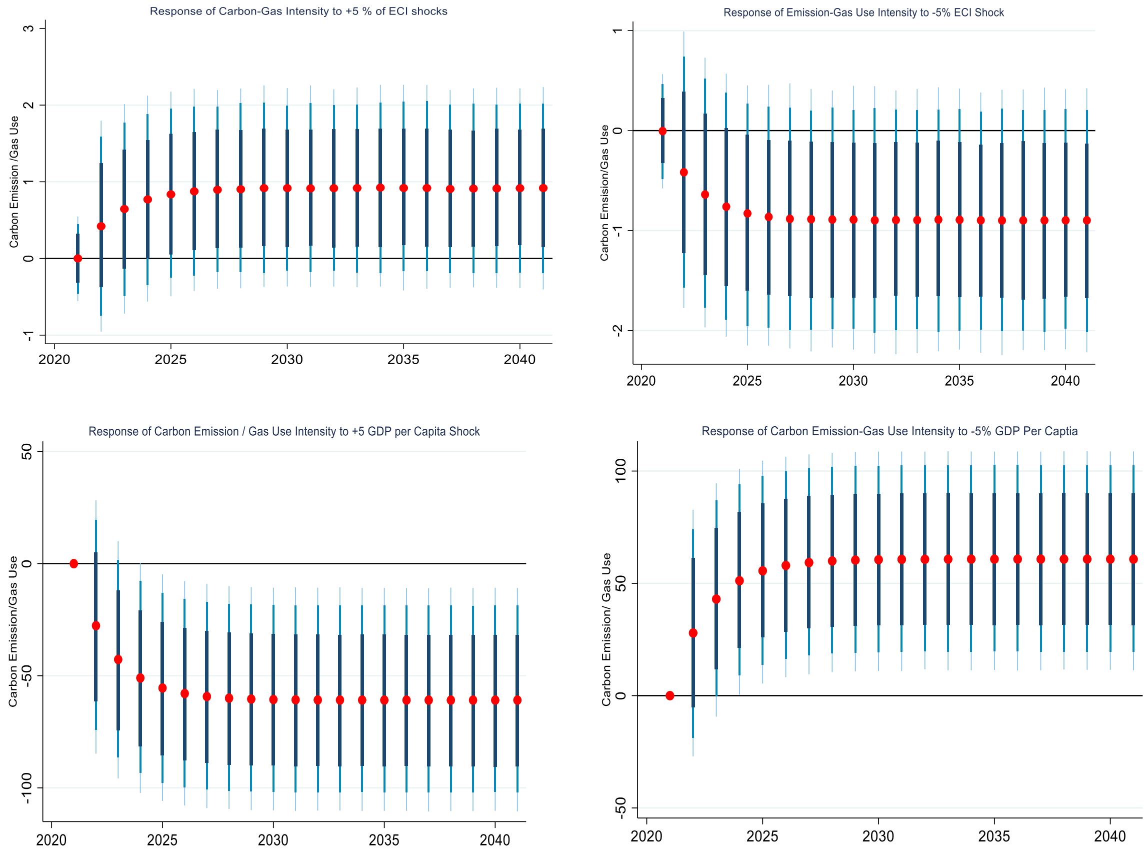

Response of Carbon-Oil Intensity to +5% ECI shock

Response of Carbon-Oil Use Intensity to -5% ECI Shock

Response of Emission-Oil Intesity to +5% GDP per Capita

Response of Carbon Emission/Oil Use to -5% GDP Per Capita

Fig. 3. Response of carbon emissions–oil intensity to ECI and economic growth.


Response of Carbon-Gas Intensity to +5 % of ECI shocks

Response of Emission-Gas Use Intensity to -5% ECI Shock

Response of Carbon Emission / Gas Use Intensity to +5 GDP per Capita Shock

Response of Carbon Emission-Gas Use Intensity to -5% GDP Per Captia

Fig. 4. Response of carbon emissions–gas intensity to ECI and economic growth.

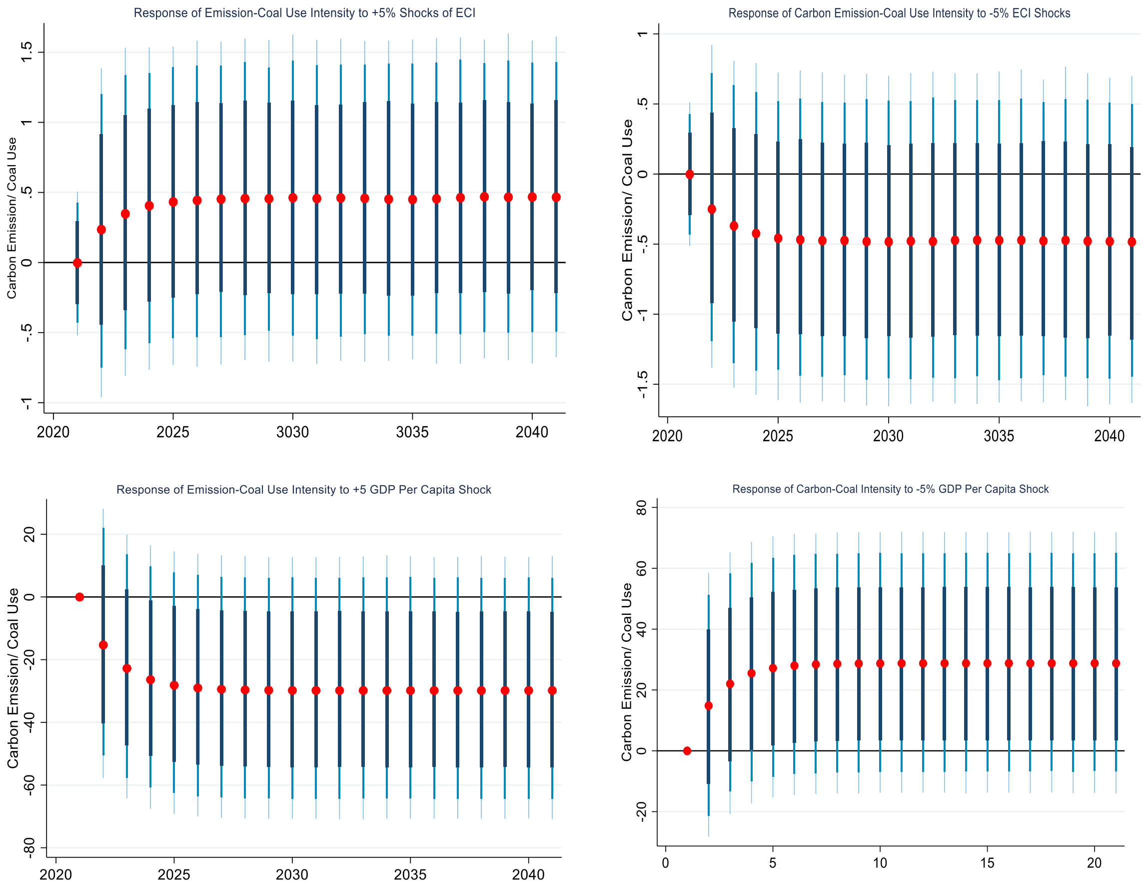


Fig. 5. Response of carbon emissions–gas intensity to ECI and economic growth.

industries is rapidly improving; therefore, any development in economic complexity does not reduce gas emissions intensity in the context of Indonesia.

Fig. 5 presents the response of emissions–coal use intensity to 5% positive and negative shocks in ECI and economic growth. A 5% positive shock of ECI fosters insignificant emissions–coal use intensity. Conversely, a negative shock of economic complexity induces a downward trend in emissions–coal use intensity, in a mirror image of the 5% positive shock. Interestingly, emissions–coal use intensity responds negatively towards 5% positive shocks in GDP per capita growth. Our result reflects the reality of higher economic growth helping the country move from a traditional production paradigm to a technology-based growth paradigm, which eventually helps to reduce overall carbon emissions intensity.

In summary, our empirical findings indicate that to achieve emissions reduction goals, Indonesia should simultaneously improve economic growth and energy efficiency by improving technology. To begin this transition, energy composition must move from coal to natural gas and oil use and eventually to cleaner energy.

5. Conclusion and policy implications

Given Indonesia's emissions reduction target, we measure the impact of economic growth and ECI on three measures of CI, including oil, gas and coal, using historical data. In the second stage, we simulate the response of carbon emissions intensities for oil, gas and coal use to economic growth and the ECI applying a DSARDL approach for a 20-year time horizon. Our investigation reveals three noteworthy findings.

First, the relationship between oil emissions intensity and economic growth contradicts the EKC hypothesis. Notably, higher economic complexity helps to curb oil emissions intensity in the long-run through technological progress in Indonesia; thus confirming our proposition that technological progress in oil use industries has experienced a significant gain in energy efficiency. Second, the gas emissions intensity and economic growth nexus validates the EKC hypothesis. Notably, ECI has an insignificant, but recognisable, role in limiting gas emissions intensity. We argue that Indonesia has significant natural gas reserves, which is a transitional energy; however, the extracted amount of natural gas fails to meet domestic demand. In addition, technological progress in gas use industries remains stagnant over time; hence, ECI appeared insignificant in influencing gas emissions intensity. Finally, increased ECI has an insignificant influence on coal emissions intensity, as the technology in coal industries has remained constant over time. Indonesia has become a leading coal exporter and user since 2000. Economic sophistication failed to replace coal energy with cleaner energy in Indonesia due to short-run economic gain; therefore, our findings indicate that Indonesia could possibly achieve the emissions reduction target by advancing ECI and quality economic growth.

Our findings regarding the influential role of the ECI in reducing oil emissions intensity indicates that Indonesia requires higher production capabilities and labour and capital underpinning the growth of a knowledge economy, such as infrastructure development, intellectual property rights, policies and skilled labour. Moreover, to achieve emissions reduction goals, Indonesia must simultaneously advance both economic growth and energy efficiency through green technology. Energy composition must initially transition from coal to natural gas and oil use and eventually cleaner energy.

CRediT authorship contribution statement

Grahita Chandrarin: Funding acquisition, Supervision. **Kazi Sohag:** Conceptualization, Formal analysis, Writing – original draft. **Diyah**

Sukanti Cahyaningsih: Writing – original draft, Investigation. **Dani Yuniawan:** Investigation.

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