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The Impact of Technological Innovation on Energy Intensity: Evidence from Indonesia

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ABSTRACT

The present study not only focuses on single measure of technological innovation but included three core dynamics of measuring technological innovations. These include research and development expenditures, High-tech exports and patents by residents. This kind of extensive examination will provide greater understanding regarding which form of technological innovation have the tendency to curtail or augment levels of energy intensity in Indonesia. The awareness derived from such broad inspection would be able to identify not only the overall contribution of technological innovations in affecting country's power intensity but highlight the specific role of each form of innovation in influencing energy intensity levels and the particular association to guide effective policy making process. The current study has adopted the refined methodology of auto-regressive distributed lags (ARDL) bound testing approach to examine the dynamic relationship among energy intensity and technology innovation with amplified understanding of the critical association to support the course of economic planning and policy making. The results of ARDL bound testing approach confirm that high technology exports, research and development expenditure and number of registered patents are strong determinants of energy inefficiency in Indonesia. Likewise, the outcomes affirm that all the three proxies of technology innovation have a constructive and negative effect on energy inefficiency in Indonesia which implies that the high technology exports, number of registered patents and R&D expenditure are the main source of reducing energy inefficiency in Indonesia in the long run and short run. Also, the results of Granger causality method confirm a bi-directional causal relationship between energy intensity and technology innovation in Indonesia.

Keywords: Energy Intensity, Technology Innovation, R&D, Indonesia
JEL Classifications: Q4, O3

1. INTRODUCTION

In the present environmental era, governments, businesses and international economies are primarily concerned towards achieving energy efficiencies and reduction in the levels of energy intensity. In this regard, several ecological policy proposals lead to stimulate the growth in technological advancements (Popp, 2001). The notion is resulted from the general perception that technological improvements through innovations generate solutions to energy dependence and thus lead to the discoveries of energy efficient technical advancements that encompass the tendency to reduce energy intensities (Bosetti et al., 2006).

Many studies discuss the link between energy and technological advancements (Gallagher et al., 2006; Cheon and Urpelainen, 2012; Ghaffour et al., 2015; Ekpung, 2014; Henry, 2014; Gideon, 2014; Danbaba et al., 2016; Edwin et al., 2017; Singh and Issac, 2018; Mukadasi, 2018). Among them, the majority of the investigations are inclined towards exploring the relationship between energy consumption and technological innovations (Sohag et al., 2015; Tang and Tan, 2013; Popp, 2001). However, in the prevailing literature, very few researches examine energy intensity and presented a lack of consensus regarding the specific link between innovations and energy's extensive usage. Therefore, the connection between energy efficient technologies and energy usage have witnessed the trend of contentious debates and ambiguous findings (Hilty and Aebischer, 2015). In this regard, a strand of literature believes that improvements in technological advancements attracts innovations and bring improvement in energy extensive behaviors and trends (Wurlod and Noailly, 2018; Garrone et al., 2018). Thus, the adherents of this belief reported that enhancement in technological innovations declines energy intensity and bring positive impact to environment by curtailing extensive energy dependence that enhances environmental pressure (Bala-Subrahmanya and Kumar, 2011; Binswanger, 2002; Ekong and Akpan, 2014; Oyaromade et al., 2014; Adepoju and Eyibio, 2016; Tsang and Yung, 2017; Hussain et al., 2019).

On the other hand, the opposite view suggests that increase in efficient technologies bring appreciation to energy usage and its intensity. In this regard, Herring and Roy, (2007) reported that there exists a positive link between efficient technological innovations and energy usage. This is on the grounds that there is immediate bounce-back impact caused by power advancements innovations that bring down the relative power prices and lead to encourage and boosting the levels of energy utilization. Likewise, there are auxiliary indirect impact of reducing power prices that induces customers to purchase more items and potentially more dominantly enhances energy intensity. Therefore, simply rising levels of technological advancements to augment efficiency is limited to diminish power utilization and intensity.

Thus, keeping in mind the unclear connection between technological innovation and energy intensity (Herrerias et al., 2016; Wurlod and Noailly, 2018; Bala-Subrahmanya and Kumar, 2011; Saudi et al., 2019; Sinaga et al., 2019), the current study seeks to explore the relationship of innovation with energy intensity of Indonesia. In doing so, the present study, unlike earlier examinations, does not merely rely on single measure of technological innovation but included three core dynamics of measuring technological innovations. These include Research and Development expenditures, High-tech exports and patents by residents. This kind of extensive examination will provide greater understanding regarding which form of technological innovation have the tendency to curtail or augment levels of energy intensity in Indonesia. The awareness derived from such broad inspection would be able to identify not only the overall contribution of technological innovations in affecting country's power intensity but highlight the specific role of each form of innovation in influencing energy intensity levels and the particular association to guide effective policy making process.

The rest of the investigation is outlines as follow. Section two will shed lights on the literary contributions on important drivers of energy intensity reductions. Section three will present utilized method for the statistical analysis. Section four will demonstrate empirical findings and interpret results. Lastly, section five will conclude the investigation and provide future implications.

2. LITERATURE REVIEW

Many studies analyzed the critical relationship between energy and technological innovations (Wurlod and Noailly, 2018; Bala-Subrahmanya and Kumar, 2011; Binswanger, 2002; Garrone et al., 2018; Berndt, 1990). In this regard, several proxies of technologies have been witnessed in the existing literature by examining innovation in the form of R&D knowledge, patents, hi-tech exports etc. On the other hand, several aspects of energy have also been discussed in many studies that considers the utilization of innovation to influence energy prices, energy dependence, energy consumption and energy production. However, very few studies analyzed the drivers of energy intensities. Among them, Fisher-Vanden et al., 2004) inspected the factors that bring reduction in the levels of energy intensity in China. In doing so, the authors analyzed the data of 25 enterprises in between 1997 to 1999. The empirical findings of the investigation indicated that trends of energy prices, innovations in terms of R&D expenditures and business reforms play significant role in influencing power intensity. In particular, the outcomes of the study suggested that energy prices, R&D and reforms possess a negative long-term association with energy intensity in China.

Similarly, Herrerias et al. (2016) also examined the association between innovation and power intensity in Chinese economy. For this, the authors analyzed the impact of foreign and indigenous innovation in predicting power intensity for a panel of thirty Chinese provinces. Analyzing the data between the period of 2006 to 2010, the results of the study found evidence of the significant association between levels of innovation and power intensity in the sampled regions. Furthermore, the outcomes indicated that increase in foreign and indigenous innovation brought decline in the trend of energy intensity in China.

Analyzing the association between financial advancements and energy intensity, Aller et al. (2018) investigated the impact several measures of financial progress on energy intensity. Utilizing the panel data for twenty eight provinces of China between the years 1999 to 2004, the findings of the analysis suggested that low performance of financial sector bring enhancements in energy intensity. In addition, the study suggested that the magnitude of the effect between the variables are reducing over time indicating that China is progressing towards curtailing rising levels of energy intensive financial systems.

Similarly, Dhakal (2009) also investigated the contribution of urban energy intensity in influencing carbon emissions in China. In doing so, the study utilized the qualitative methods to examine the role of urban energy use in enhancing carbon emanations, particularly larger cities and their measures to stop increasing trends of environmental degradation. The findings of the study reported that urbanization contributed 84% power usage. Furthermore, the investigation revealed that larger cities of the country having the population of just 18% of the total country's population, resulted in enhancing carbon emission by 40% and played major role in China's environmental deterioration.

Moreover, in a panel investigation, Wurlod and Noailly (2018) examined the role of sustainable innovation in predicting energy intensity of OECD economies. For this, the authors used the data of fourteen industries for a sample of seventeen OECD nations in between 1975 and 2005. The results of the empirical investigation supported the evidence of negative link between sustainable innovation utilizing the proxy of green patents and energy intensity for the sampled countries. In particular, the findings elaborated that 1% increase in sustainable innovation tends to decline energy intensity by 0.03%. Analyzing the trends of energy intensity among the eastern and western countries of Europe, Nielsen et al., (2018) analyzed the presence U-curve in the sampled countries. The authors of the study after analyzing trends of energy intensity reported that eastern and western part of Europe is rich in coal reserves and utilization as compared to the northern and southern Europe. Furthermore, the results of the study find evidence of the inverted U-shaped curve in eastern and western Europe. On the other hand, northern and Southern have witnessed the declining trends of energy intensities. Comparing the energy intensity trends within eastern and western part of the continent, the outcomes reported that augmentation of power intensity was initiated fifty years earlier in the western part as compare to the eastern Europe.

Similarly, Voigt et al. (2014) also analyzed the levels of energy intensity and the influencing factors in forty industrialized nations. The study utilized the data from the period of 1995 to 2007. The results of the study concluded that declines in the trends of energy intensity of the majority sampled countries was majorly attributed to increase in technological advancements. On the other hand, in countries such as, Japan, Mexico, United States, Brazil, Taiwan and Australia, changes in the economic structure have been identified as the significant contributor of declining energy intensities.

In Malaysia, Sohag et al., (2015) analyzed the relationship between power intensity, innovation, growth and trade of the country. The study used the time-series data from the period of 1985 to 2012. In order to perform empirical investigations, the study applied the technique of ARDL bound testing. The results of the analysis suggested that, in short run, economic development and technological innovation is significant to influence energy usage, however, the results of trade openness are insignificant to impact energy usage in Malaysian economy. In particular, the result indicated that increase in output growth brought positive impact on energy usage, but, technological innovation carried negative relationship with power utilization in short run. The findings of long-run effects suggested that both trade openness and output development have significant positive association with energy usage. In addition, technological innovation was found to bring negative effect on the levels of energy usage in Malaysian economy in long-run.

On the other hand, Hartono and Resosudarmo, (2008) examined the case of government's policies regarding energy reduction and energy efficiency in Indonesia. Applying the energy social accounting matrix (SAM) method, the authors find evidence that governments preference for energy reduction underlies the tendency to impact income levels as it brought negative influence on household income. Furthermore, the authors find strategies for energy efficiency to be more productive, particularly in Indonesian industrial sector, in fulfilling energy intensity goals as the former is crucial in curtailing power intensity without undermining growth process compare to energy reduction policies.

Likewise, Popp (2004) also examined the role of technological innovation in influencing energy usage in United States. In order to measure technological innovation, the author utilized the measure of patents data in between 1958 and 1991. The findings of the study reported that technological innovation is significant to influence energy usage suggesting that increase in innovation tends to decline energy dependence. Similarly, inspecting the impact of power prices on innovation, Popp (2002) investigated the influence of energy prices on energy-efficient innovations in United States of America. In doing so, the study utilized the data from the period of 1970 to 1994. The results of the study found that energy price and knowledge quality are significant to bring positive impact on energy efficient innovation.

Similarly, In India, Subrahmanya and Kumar, (2011) analyzed the relationship between energy intensity and innovation of Banglore. The results of the analysis suggested that, technological innovation is significant to influence energy intensity in small and medium enterprises (SMEs) of the country. In particular, the findings indicated that increase in innovation brought decline to the levels of energy intensity. Furthermore, the results also suggested that in addition to innovation, the other drivers of energy intensity are labor productivity, sales growth and technical entrepreneurship for Indian SMEs. Furthermore, Kratena (2007) examined the association between technological changes, power intensity and investments in Spain, Italy and Finland. Evaluating the country from 1970 to 2004 for Italy, 1980 to 2004 for Spain and 1970 to 2003 for Finland, the author analyzed twenty eight industries of the sampled countries. The findings of the investigation reported that decline in energy intensity accompanied by technological innovations but the major contribution in played by increase in energy prices (Kobayashi et al., 2013; Ekong and Akpan, 2014; Asyraf, 2014; Behera, 2015; Vafaeirad et al., 2015; Ozturk and Ozturk, 2018; Ali and Haseeb, 2019; Haseeb et al., 2018; Suryanto et al., 2018).

3. METHODOLOGY

For data investigation, we use at the dynamic association between energy intensity and technology innovation (using three proxies). The framework for the current study is as follows

$$EINT = \beta_0+\beta_1(HTEC)+\beta_1(RDEX)+\beta_1(PATE)+\varepsilon_t$$

Where, ε_t is the error term, *EINT* denotes the energy intensity which is calculated by the ratio of primary energy use and purchasing power parity of gross domestic product and measured in (MJ/GDP PPP). *HTEC* is the high technology exports which is measured in constant US$. *RDEX* is the research and development expenditure which is also measured in constant US$. However, *PATE* represents patents and it is measured by the number of patents registered by the individual. The annual sample data for the current examination is gathered from the period of 1981 to 2017. Entire sample data are collected from World Development Indicators (World Bank).

3.1. Unit Root Tests

For the data analysis, we apply unit root test to confirm the stationarity features of the considered time series as used in previous researches (Sharif et al., 2018; Afshan et al., 2018). For this purpose, the present research uses different well-known unit root techniques that are Augmented-Dickey Fuller (ADF) and Philip-Perron (PP) unit root tests. For checking the stationarity features, we initially check the sample on level series and finally of first differential series.

3.2. ARDL Bound Testing Cointegration Analysis

For exploring the impact of high technology exports, research and development expenditure and number registered patents on energy intensity in Indonesia, we apply the Auto Regressive Distributed Lag (ARDL) approach of long run linkages that was presented by Pesaran and Pesaran (1997); Pesaran and Shin (1999); Pesaran et al. (2001; 2000). The ARDL philosophy is connected with the assistance of unobstructed vector error correction framework to explore the long-run connection between high technology exports, research and development expenditure, number registered patents and energy intensity in Indonesia. This strategy has a couple of preferences on past long run relationship methods (like J.J cointegration and Pearson Correlation). The current method might be useful whether the focus time series factors are absolutely I(0), I(1) or comparably co-consolidated (Sharif and Raza, 2016). The ARDL methodology is proposed for above examination is given beneath:

$$\Delta EINT = \varphi_0 + \varphi_1 \sum_{t=1}^{p} EINT_{t-1} + \varphi_2 \sum_{t=1}^{p} HTEC_{t-1} + \varphi_3 \sum_{t=1}^{p} RDEX_{t-1} + \varphi_4 \sum_{t=1}^{p} PATE_{t-1} + \gamma_1 EINT_{t-1} + \gamma_2 HTEC_{t-1} + \gamma_3 RDEX_{t-1} + \gamma_4 PATE_{t-1} + \mu_t$$

Where, φ_0 is consistent period and μ_t is the backend noise period, the error correction range is disclosed to by the sign of summation however, the other extent of the equation relates to long-run connections. The Schwarz Bayesian criteria (SBC) is utilized to take a maximum lag length decision for every variable used in the current study. In ARDL method, initially the current study finds out the F-stats significance by using the fitting ARDL model. At that point, the Wald (F-stats) technique is utilized to examine the long-run connection between the components. In long run connection between EINT, HTEC, RDEX and PATE are assessed, by then the current examination decided the long run constraint by using resultant structure.

$$EINT_t = \zeta_0 + \zeta_1 \sum_{i=1}^{p} EINT_{t-1} + \zeta_2 \sum_{i=1}^{p} HTEC_{t-1} + \zeta_3 \sum_{i=1}^{p} RDEX_{t-1} + \zeta_4 \sum_{i=1}^{p} PATE_{t-1} + \mu_t$$

Primarily, in the present research if the long-run connection between EINT, HTEC, RDEX and PATE is confirmed with indication then we calculate the beta coefficient of the short-run by using the beneath equation:

$$EINT_t = \delta_0 + \delta_1 \sum_{i=1}^{p} EINT_{t-1} + \delta_2 \sum_{i=1}^{p} HTEC_{t-1} + \delta_3 \sum_{i=1}^{p} RDEX_{t-1} + \delta_4 \sum_{i=1}^{p} PATE_{t-1} + nECT_{t-1} + \mu_t$$

Lastly, the error correction model (ECM) establish the swiftness of variation allow to capture the long-run symmetry since of short-run changes. The *n* is the valuation of ECT in the system that explain the swiftness of variation (Sharif et al., 2018; Afshan et al., 2018).

3.3. Granger Causality Method

In this study, we distinguish the causal linkages between the predefined factors, the current examination proposed to use the Granger causality method. The technique for Granger causality involves various advantages as opposed to other causal estimation, especially in the time-arrangement analysis. This embraces the choice of using the said examination for investigating the causal association between high technology exports, research and development expenditure and number of patents registered in Indonesia are reliable and progressively dependable in contrast with the prior investigations.

4. DATA ANALYSIS AND DISCUSSION

The current section clarifies about the data examination. Basically, we used stationary test to insist the stationary property of the considered variables. The results of unit root test are represented in Table 1. We utilized two distinctive unit root tests to be explicit (ADF and PP) test to affirm the stationary features of the variables. The results attest that EINT, HTEC, RDEX and PATE are not stationary at level and become stationary at first differential level. Technically speaking, from the outcomes of unit root test, we can derive that series of the significant number of variables demonstrate the stationary features and allow for continuing to the long run examination.

Also, to explore the long term connection among EINT, HTEC, RDEX and PATE in Indonesia, the ongoing examination utilized the unique methodology of ARDL. In doing as such, the underlying step is to determine the most extreme lag length of all variable chose for this examination. The order of the highest lag length is chosen by the standards of SBC as referenced before. In this way, the outcomes of the ARDL long-run affiliation results are exhibited in Table 2.

The outcomes of Table 2 certify the null hypothesis declaring that not cointegration between the variable is rejected. This is due to the coefficient of the F-stats is greater than UBC coefficient at 1% significance level. Therefore, in the favor of acknowledgment of the alternate hypothesis which suggests that there is a substantial long-run connection occur among EINT, HTEC, RDEX and PATE in Indonesia (Table 3).

The findings of ARDL bound testing cointegration test, in this way, confirm the robustness of achieved outcomes. It is demonstrated that a genuine long-run relationship shows between EINT, HTEC, RDEX and PATE in Indonesia. Likewise, after to asserting the sign of long run relationship between the considered variables, the following stage of the examination is to distinguish the ARDL framework with the purpose of identifying the beta estimation of long-short run time. For this reason, the present examination gauges the lag length order of all the variables used in this study by the base estimation of SBC.

Table 1: Results of unit root test

Variables	ADF unit root test				PP unit root test			
	I (0)		I (1)		I (0)		I (1)	
	C	C&T	C	C&T	C	C&T	C	C&T
EINT	1.390	1.431	−5.393	−5.399	1.222	1.251	−5.358	−4.617
HTEC	0.360	0.445	−4.351	−4.214	0.352	0.447	−4.645	−4.580
RDEX	−0.223	−0.220	−4.616	−5.028	−0.210	−0.244	−4.906	−4.887
PATE	−1.467	−1.357	−4.574	−4.634	−1.374	−1.351	−4.583	−4.613

Source: Authors' estimations. The critical values for ADP and PP tests with constant (C) and with C&T 1%, 5% and 10% level of significance are −3.711, −2.981, −2.629 and −4.394, −3.612 and −3.243 respectively. ADF: Augmented-Dickey fuller, C&T: Constant and trend

Table 2: Results of bound testing for cointegration

Lags order	AIC	HQ	SBC	F-test statistics
0	−3.359	−4.039	−3.937	54.382*
1	−4.279*	−4.224*	−4.034*	
2	−3.468	−3.694	−3.292	
3	−3.279	−3.049	−3.121	

Source: Authors' estimation. *1% level of significant

Table 3: Results of lag length selection

Lag	0	1	2	Nominated lags
	SBC	SBC	SBC	SBC
HTEC	2.482	−3.377*	−2.993	1
RDEX	1.383	−3.003*	−2.782	1
PATE	3.428	−4.381*	−3.843	1

Source: Authors' estimation. *Indicate minimum SBC values

The results of long run estimations are shown in Table 4. The findings of ARDL confirm that high technology exports, research and development expenditure and number of registered patents are significant determinants of energy intensity in Indonesia. In this manner, the results certify that all the three proxies of technology innovation which are (high technology exports, number of registered patents and research and development expenditure) have a negative and significant impact on energy intensity in Indonesia over the long run. Likewise, it very well shows that number of registered patents have a highest negative impact on energy intensity followed by high technology exports and research and development expenditure in Indonesia.

The results of short run coefficient of ARDL investigation is exhibited in Table 5. The outcomes affirmed a significant short-run association between EINT, HTEC, RDEX and PATE in Indonesia. The proportion of error term is meaning near −0.269 suggest that practically 26.9% of adjustment is change in the current year. In addition, the outcomes likewise propose the important impact of high technology exports, number of registered patents and research and development expenditure in Indonesia in short run too.

The results of Granger-causality show in Table 6. The results define that there a causal relationship among all the variables with energy intensity. The findings confirm that high technology exports, research and development expenditure and number of registered patents have a bi-directional causal relationship with energy intensity which means causality is running in both directions.

Table 4: Results using ARDL approach (long run)

Variables	Coeff.	t-stats	Prob.
C	0.228	3.938	0.000
EINT (−1)	0.234	4.254	0.000
HTEC	−0.328	3.584	0.000
HTEC (−1)	0.032	4.083	0.000
RDEX	−0.302	5.224	0.000
RDEX (−1)	−0.173	1.960	0.050
PATE	−0.399	4.680	0.000
PATE (−1)	−0.110	3.208	0.000
Adj. R^2	0.893		
D.W stats	1.873		
F-stats (Prob.)	2375.327 (0.000)		

Source: Authors' estimation

Table 5: Results using ARDL approach (short run)

Variables	Coeff.	t-stats	Prob.
C	−0.215	4.093	0.000
ΔEINT (−1)	0.047	1.801	0.074
ΔHTEC	0.268	4.237	0.000
ΔHTEC (−1)	0.036	1.598	0.170
ΔRDEX	0.193	5.324	0.000
ΔRDEX (−1)	0.023	0.287	0.774
ΔPATE	0.221	1.960	0.050
ΔPATE (−1)	0.003	1.182	0.238
ECM (1)	−0.269	−4.325	0.000
Adj. R^2	0.824		
D.W stats	1.883		
F-stats (Prob.)	2201.321 (0.000)		

Source: Authors' estimation

5. CONCLUSION AND RECOMMENDATION

The discussion between energy efficient technologies and energy usage have witnessed the trend of contentious debates and ambiguous findings. Contrary to the apparent view that enhancement in technological innovations tends to improve energy efficiency and bring positive impact to environment by curtailing energy intensity that enhances environmental pressure, the opposite view suggests that increase in efficient technologies on the other hand bring appreciation to energy usage and intensity. Likewise, there are auxiliary indirect impact of reducing power prices that induces customers to purchase more items and potentially more dominantly enhances energy intensity. Therefore, simply rising levels of technological advancements to augment efficiency is limited to diminish power utilization and intensity.

Thus, keeping in mind the ambiguous link of technological innovation with energy intensity, the current study seeks to

Table 6: Results of Granger-Causality test

Null hypothesis	F-Statistic	Prob.
EINT does not granger cause HTEC	4.163	0.000
HTECH does not granger cause ENT	8.059	0.000
EINT does not granger cause RDEX	5.109	0.000
RDEX does not granger cause EINT	5.176	0.014
EINT does not granger cause PATE	8.051	0.000
PATE does not granger cause EINT	3.252	0.058
HTEC does not granger cause RDEX	3.999	0.021
RDEX does not granger cause HTEC	4.822	0.009
HTEC does not granger cause PATE	3.532	0.328
PATE does not granger cause HTEC	4.076	0.019
RDEX does not granger cause PATE	8.932	0.000
PATE does not granger cause RDEX	5.388	0.000

Source: Author's estimation

explore the relationship of innovation with energy intensity of Indonesia. In doing so, the present study, unlike earlier examinations, does not merely rely on single measure of technological innovation but included three core dynamics of measuring technological innovations. These include Research and Development expenditures, High-tech exports and patents by residents. This kind of extensive examination will provide greater understanding regarding which form of technological innovation have the tendency to curtail or augment levels of energy intensity in Indonesia. The awareness derived from such broad inspection would be able to identify not only the overall contribution of technological innovations in affecting country's power intensity but highlight the specific role of each form of innovation in influencing energy intensity levels and the particular association to guide effective policy making process.

The current study has adopted the refined methodology of auto-regressive distributed lags (ARDL) bound testing approach to examine the dynamic relationship among energy intensity and technology innovation with amplified understanding of the critical association to support the course of economic planning and policy making. The results of ARDL bound testing approach confirm that high technology exports, research and development expenditure and number of registered patents are strong determinants of energy inefficiency in Indonesia. Likewise, the outcomes affirm that all the three proxies of technology innovation have a constructive and negative effect on energy inefficiency in Indonesia which implies that the high technology exports, number of registered patents and R&D expenditure are the main source of reducing energy inefficiency in Indonesia in the long run and short run. Also, the results of Granger causality method confirm a bi-directional causal relationship between energy intensity and technology innovation in Indonesia.

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