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Impacts of Internet Usage on CO_2 Emissions under The Moderation of Innovative Activities: The Case of Southeast Asian Countries

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Abstract

Governments of many countries have been paying more attention to pollution and its negative impacts on the economic development of their countries. Using random-effects and fixed-effects models with a data set from the World Bank, this research aims to assess innovative activities' significance in moderating internet use's impact on CO_2 emissions in seven Southeast Asian countries from 1996 to 2020. The findings reveal that internet use is positively associated with CO_2 emissions in Southeast Asian countries and that innovative activities can mitigate the effects of internet use on CO_2 emissions. Based on the research results, the authors believe that, in addition to the

growing popularity of the internet, the governments of Southeast Asian countries should have policies in place to promote innovative activities that reduce CO_2 emissions while maintaining their sustainable economic development.

Keywords: Innovative activities; Internet usage; CO_2 emissions; Southeast Asia

1. Introduction

Environmental pollution is regarded as one of the most severe issues by governments worldwide and is becoming increasingly complicated. Climate change, a consequence of the increase in CO_2 emissions, is of interest to many scholars around the world (Azam et al., 2020; Jian et al., 2019; Muhammad & Long, 2021; Roinioti & Koroneos, 2017; Shahbaz et al., 2019). Meanwhile, many other researchers also demonstrate that innovative activities are critical to reducing CO_2 emissions (Balsalobre-Lorente et al., 2018; Chen & Lee, 2020; Dauda et al., 2019; Nguyen & Do, 2021; Santra, 2017; Wang et al., 2018; Yii & Geetha, 2017). Especially recent financial development plays an important role in mitigating environmental pollution since it helps innovative technological businesses to access funds for adopting new technologies and use energy more efficently (Bayar et al., 2020; Jian et al., 2019; Nguyen, 2021).

Nowadays, the internet, which represents modern information technology, has been successfully incorporated into all spheres of social life. Furthermore, it has a significant impact on the ecological environment in addition to being essential for economic development. While several studies demonstrate the impacts of internet usage on energy consumption (Freidin & Burakov, 2018; Rahimi & Rad, 2017; Salahuddin & Alam, 2015), other studies investigate the effects of internet usage on CO_2 emissions (Ozcan & Apergis, 2018; Salahuddin et al., 2016; Wang & Xu, 2021). The internet

dependency theory posits that the internet changes users› cognition, behavior, and emotions, altering their social interaction style and self-awareness. As a result, online environmental education has the potential to have a huge impact on consumer behavior. People are increasingly opting for lifestyles that are greener, more efficient, and friendlier to the environment, which is vital for reducing CO_2 emissions and achieving green sustainable development (Zhihong et al., 2018). Furthermore, recent attention has been focused on the environmental impact of innovative activities. The innovation process encourages the use of clean energy, which reduces carbon emissions directly. Alternatively, innovation may lead to an increase in carbon emissions as a result of the rapid economic expansion. Recent research has found that innovative activities have diverse effects on sustainable development and CO_2 emissions in various country settings (Cai et al., 2013; Chen & Lee, 2020; Dauda et al., 2019; Faber & Hesen, 2004). In short, it is debatable and needs further investigation if and how innovative activities affects carbon emissions. Besides, internet usage can promote the spread of knowledge and make information flow more quickly and inexpensively through lowering information asymmetry in society. Some researchers agree that acccess to the internet lowers the cost of publishing information, which encourages the filing of more patents in the nation (Xu et al., 2019; Paunov & Rollo, 2016). Existing research appears to downplay the relevance of the interaction between internet usage and innovation, which should be viewed in connection with the environment. Therefore, this study aims to explore empirically whether innovation can moderate the impacts of internet use on the CO_2 emissions in Southeast Asian countries.

The Southeast Asia region is notable to the researchers in terms of environmental pollution and ICT development for several reasons. First, Southeast Asia consists of 11 countries, most of which are classified as low-average income countries (World Bank, 2022). These countries heavily depend on fossil fuels to achieve their industrial development goals, which consequently have negative impacts on the environment. On one hand,

emissions (measured by CO_2 plus methane emmissions) per capita are higher in the developed countries comparing with those in the LDCs (Islam & Chowdhury, 1997). This gap has been narrowed as the industrialization process gets momentum in the LDCs (Saboori & Sulaiman, 2013). On the other hand, emissions and energy consumption per unit GDP are higher in the LDCs. In fact, Southeast Asia, where the most industrialized LDCs are located, shows a much higher figure in energy consumption and emissions per unit GDP (Islam & Chowdhury, 1997; Vo et al., 2019). In other words, the environmental costs of economic growth in the LDCs are generally greater than in others. Second, in recent years, Southeast Asia has been a booming emerging market with 400 million internet users. Except for Laos, Myanmar, and Timor-Leste, the internet penetration ratio in Southeast Asia is over 70% (Leander von Kameke, 2023). The rapid growth of digital technologies and internet access in Southeast Asia helps to promote innovative activities and economic growth in these countries (Erh, 2021). In this regard, creative initiatives have the potential to contribute to the reduction of the environmental issues.

This study makes several contributions to the literature. *First*, this study adopted a new approach with the involvement of innovative activities as a moderator to provide more evidence on the relationship between internet usage and CO_2 emissions, whereas previous studies did not include this factor (Ozcan & Apergis, 2018; Salahuddin et al., 2016; Wang & Xu, 2021). *Second*, this study contributes to a complete understanding of the relationships between internet use, innovative activities, and CO_2 emissions, which has important implications for Southeast Asia countries pursuing their emission reduction goals.

The rest of the paper is organized as follows. In the second section, a literature review is presented. Methodology and data are outlined in Section 3. The empirical findings are discussed in Section 4, which follows. Section 5 concludes.

2. Theoretical basis, empirical evidence, and research hypothesis

2.1. Theoretical basis

The environmental Kuznets curve (EKC) hypothesis explains the correlation between various measures of environmental degradation or environment and economic growth presented by per capia income. During the early stages of economic expansion, pollutant emissions increase and environmental quality falls. However, once per capita income reaches a certain threshold, the tendency reverses, and economic growth results in environmental improvement thanks to technological innovation (Dong et al., 2020; Nguyen & Do, 2021). The development of scientific research and social progress has led to a recognition of technological innovation as one of the key forces behind economic growth and the cornerstone of climate control (Balsalobre-Lorente et al., 2018; Chen & Lee, 2020). We are living in the fourth industrial revolution, which should assist to lower pollution levels through the process of creative destruction and reshaping industrial structures to become more ecologically friendly. Besides, in this revolution, internet technology has gradually spread and penetrated different social and economic fields. According to the internet dependency hypothesis, internet access may help to increase consumers' awareness of environmental issues, changing their lifestyle and improving environmental quality (Zhihong et al., 2018). Furthermore, the adoption of internet technology in the manufacturing sector can enhance energy usage efficiency and minimize CO_2 emissions (Cai et al., 2013; Ozcan & Apergis, 2018; Wang & Xu, 2021). The development of smart cities and intelligent transportation systems using big data, blockchain, and other internet technologies would ignificantly reduce CO_2 emissions (Wang & Xu, 2021). In contrast, the rapid development of the internet and widespread usage of connected gadgets increases power consumption, which may have a negative influence on the environment (Salahuddin et al., 2016). Can innovative activities and internet usage

mitigate CO_2 emissions while promoting economic development? Do innovative activities moderate the impact of internet usage on CO_2 emissions? These questions need to be further examined empirically.

2.2. Empirical evidence and research hypotheses

2.2.1. Innovative actitivities and CO_2 emissions

Many studies have emphasized innovation as the solution to environmental pollution (Balsalobre-Lorente et al., 2018; Chen & Lee, 2020; Dauda et al., 2019; Nguyen & Do, 2021.; Nguyen, 2021; Santra, 2017; Wang et al., 2018; Yii & Geetha, 2017) because new technological inventions can facilitate countries' transition from depending on fossil fuels to using more environmentally friendly sources of energy thereby reducing CO_2 emissions (Foxon, 2011; Fernández et al., 2018). In other words, promoting innovation will result in introducing new energy-efficient technologies and eco-friendly fuel sources, which may lead to CO_2 emissions being under control. Taking these arguments into account, the authors developed the following research hypothesis:

Hypothesis H1: Innovative activities are inversely associated with CO_2 emissions in Southeast Asian countries.

2.2.2. Internet usage and CO_2 emissions

There are conflicting findings regarding the relationship between internet usage and CO_2 emissions. Some researchers argue that internet usage automates the manufacturing process, increasing production efficiency and lowering energy consumption (Cai et al., 2013; Khan et al., 2020; Ozcan & Apergis, 2018). For instance, Cai et al. (2013) argued that the development of information technology, which will result in more efficient use of energy in all economic sectors, can be a potential solution to CO_2 emissions. Ozcan and Apergis (2018) conducted a study on the impacts of internet use on CO_2 emissions of 20 emerging countries between 1990 and 2015. The results show that the increase in internet usage contribute to the reduction of CO_2

emissions. Similarly, Khan et al (2020) reported that internet access enables the development of a home energy management controller and the reduction of energy consumption when they explore the determinants of CO_2 emissions in G7 countries from 1990 to 2017. Besides, the ease of access to the internet may accelerate the transitions of traditional commercial activities to online shopping, e-commerce, and remote working activities, which will significantly reduce environmental pollution (Fuchs, 2008; Romm, 2002).

On the other side, some scholars claimed that internate usage does not help to reduce CO_2 emissions. For example, Fuchs (2008) argued that new information and communication technologies have negative impacts on environmental quality because huge energy consumptions generate harmful emissions during the process of production and implementation of these technologies. Salahuddin et al. (2016) examined the short- and long-term effects of internet use and economic growth on CO_2 emissions in OECD countries between 1991 and 2012. The findings show that internet use is positively related to CO_2 emissions. When analyzing the impact of human resources and internet use on CO_2 emissions of 70 countries from 1995 to 2018, Wang and Xu (2021) also proved that the internet use has a positive correlation with CO_2 emissions when a country has low human resources and vice versa. Various studies also showed that the operation of new internet-connected devices consumes a lot of energy. Salahuddin and Alam (2015), for example, used annual time series macro data in Australia from 1985 to 2012 to estimate the short-term and long-term effects of internet use and economic growth on electricity consumption. The authors figured out that internet use and economic growth stimulate electricity consumption in this country. Rahimi and Rad (2017) examined the effects of internet use and economic growth on electricity consumption in eight developed countries from 1990 to 2013 and discovered that increased internet use leads to increased electricity consumption. Likewise, Freidin and Burakov (2018) examined the long-term and short-term effects of economic growth and internet use on electricity consumption in Commonwealth of Independent States (CIS)

countries from 1991 to 2017. The findings indicate that internet use has a long-term impact on electricity consumption. According to an International Energy Organization (IEA) report, the demand for energy in many emerging markets has steadily increased in recent years as a result of rapid urbanization, which has increased CO_2 emissions globally (International Energy Agency, 2021). In other words, increased internet use in developing countries will result in increased energy demands, resulting in increased CO_2 emissions in these countries. Based on these facts, the hypothesis about the impact of internet use on CO_2 emissions is as follows:

Hypothesis H2: Internet usage is positively associated with CO_2 emissions in Southeast Asian countries.

2.2.3. Innovation moderates the impact of interenet usage on CO_2 emissions.

Internet facilitates the dissemination of increasingly large sets of knowledge and information to large populations. By expanding access to ideas, the internet may stimulate innovation, as new combinations of existing knowledge spark innovation (Arthur, 2007). Paunov and Rollo (2016) also confirmed the positive knowledge spillover effects from industries' adoption of the internet on firms' productivity and innovation performance using 50,013 firm observations for 117 countries from 2006 to 2011. Utilizing a county-level data set in the United States, Xu et al. (2019) employed three forms of regression and found a positive correlation between internet availability and the number of patents filed in a particular county. Therefore, countries with greater internet access will work more quickly on digital transformation and innovative endeavors, reducing CO_2 emissions indirectly. Based on the above analysis, the authors proposed the following research hypothesis:

Hypothesis H3: Internet use is inversely correlated with CO_2 emissions in Southeast Asian countries under the moderation of innovation.

3. Research Methods

3.1. Research data

This study's data was collected between 1996 and 2020 from seven Southeast Asian countries, including Vietnam, Singapore, Thailand, Indonesia, Malaysia, Brunei, and the Philippines. Only seven of the eleven Southeast Asian countries were selected because the remaining countries lacked sufficient data on innovation activities, i.e., patent applications and internet access; therefore, including them in the research could have affected the estimations of the research model. In addition, the authors chose to collect data beginning in 1996 because some nations lacked information on the number of internet users in their populations prior to that year. Until 2020, data on the innovative activities of these nations cannot be collected. The authors chose 1996-2020 to collect sufficient data on CO_2 emissions per capita, patent applications, per capita income, and ratios of foreign direct investments to GDP, export to GDP, and import to GDP, which was provided by the World Bank (World Bank, 2022).

3.2. Research model

To assess the role of innovation in moderating the influence of internet usage on CO2 emissions in some Southeast Asian countries, we employ the following estimation model:

$$LCO_{2i,t} = \beta_0 + \beta_1 PAT_{i,t-1} + \beta_2 IU_{i,t-1} + \beta_3 PAT*IU_{i,t-1} + \beta_4 LGPP_{i,t-1} + \beta_5 TO_{i,t-1} + \beta_6 FDI_{i,t-1} + \mu_{i,t}$$

CO_2: National CO_2 emission, measured by the country's CO_2 emission per capita (Ozcan & Apergis, 2018; Nguyen & Do, 2021; Nguyen, 2021).

PAT: National innovation, measured by the number of national patent applications (Tee et al., 2014; Nguyen, 2021). We choose the number of patent applications to measure the innovation activity of a country rather than other measures such as the number of patents (Faber & Hesen, 2004; Smith, 2004)

or the number of R&D researchers per capita for several reasons: First, the available data from the World Bank do not meet the criteria for calculating the number of R&D researchers in Southeast Asian nations. Second, not every invention is patentable (Griliches, 1990). Because some new types of technology are not patented, the patent index may miss many unpatented inventions and inventions (Kleinknecht et al., 2002). Consequently, it may be insufficient to use the number of patents (granted) as a metric of innovative activities. Several studies, including Varsakelis (2006), Ang (2010, 2011), Nguyen (2021), Nguyen and Do (2021), have proposed using the number of patent applications to assess a country's innovation activity. Finally, we assert that national innovation is defined as all innovation activities of residents that are shaped by transformation, improvement, and other inputs, resulting in outputs as measured by the number of patent applications for that country.

IU: Internet usage, measured by the proportion of people using the internet to the total population (Ozcan & Apergis, 2018).

PAT*IU: the interaction variable of innovation and internet use, measured by the product of the number of national patent applications and the ratio of internet users to the total population.

The control variables in the study include economic development (LGPP), trade openness (TO), and the ratio of foreign direct investment in a country to GDP (FDI). Specifically, it is as follows: LGPP is an economic development variable, measured by the natural logarithm of GDP per capita (Ozcan & Apergis, 2018); TO is the trade openness variable, measured by the ratio of total exports and imports to GDP (Ozcan & Apergis, 2018); FDI is measured by the ratio of foreign capital invested in a country to GDP (Dauda et al., 2019).

3.3. Testing and model selection

In this study, we apply the fixed-effects model and the random-effects model, two common regression techniques for panel data analysis. They can help control the effects on a single country (Wooldridge, 2001).

Then, the Hausman test is used to determine whether Fixed-effects model or Random-effects model would be the appropriate one for this research. Other tests are also conducted to investigate the model's defects. For instance, Variance Inflation Factor (VIF) is used for assessing multicollinearity (Hair et al., 2006) and Wooldridge test for tracking autocorrelation (Wooldridge, 2005). To address the issues of autocorrelation and heteroskedasticity in the research, we employed Driscoll and Kraay›s Robust standard errors approach for panel regression (1998).

4. Research results and discussion

4.1. Description of data

The authors analyzed the data collected from World Bank to describe the variables in the research model, which include PAT (the number of patent applications), PATN (the number of patent applications by non-residents), PATR (the number of patent applications by permanent residents), PATP (patent applications per capita), CO_2 (CO_2 emissions per capita), IU (the ratio of internet users to total population), TO (trade openness), GPP (per capita income), and FDI (the ratio of foreign direct investment to GDP).

Table 1. Descriptive statistics of variables

Variable	Number of observations	Average Value	Standard deviation	Min Value	Max Value
CO_2	170	5.422	5.008	0.449	19.499
PAT	170	4,975.771	3,239.611	21	14,136
PATN	170	4,231.394	2,841.862	5	12,409
PATR	170	744.376	1,346.062	0	11,487
PATP	170	0.00036	0.0006	0.000008	0.0034
IU	170	33.9049	28.8699	0.0001	95
GPP	170	13,872.13	17,024.61	785.533	61,173.9
TO	170	148.242	98.629	32.975	437.326
FDI	170	5.5784	6.647	-2.757	32.169

Source: Compiled by the authors

According to Table 1, the average CO_2 emission per capita of seven Southeast Asian countries in the period 1996-2020 was 5,422 tons/person. Meanwhile, the research by Nguyen (2021) mentions that the average CO_2 emission per capita of 14 Asian countries was 4,893 tons/person in the period 1995-2018. Besides, the average number of patent applications of seven Southeast Asian countries in the period 1996-2020 was 4,975.771 while it is indicated in the research by Nguyen (2021) that the average number of patent applications of 14 Asian countries in the period 1995-2018 was 73,839.84. It indicates that the CO_2 emission of Southeast Asian countries is higher than that of Asian nations, while the innovation level of Southeast Asian nations is lower. Table 1 reveals that the average number of patent applications by non-residents is 4,231.394, which is significantly higher than the average number of patent applications by domestic residents, which is 744,376. This comparison revealed that Southeast Asian nations are heavily reliant on foreign firms.

Table 2. Correlation matrix

Variable	CO_2	PAT	IU	PAT*IU	LGPP	TO	FDI
CO_2	1.000						
PAT	-0.135*	1.000					
IU	0.499***	0.415***	1.000				
PAT*IU	0.148*	0.808***	0.751***	1.000			
LGPP	0.868***	0.274***	0.611***	0.49***	1.000		
TO	0.325***	0.569***	0.461***	0.64***	0.62***	1.000	
FDI	0.324***	0.475***	0.381***	0.626***	0.6***	0.801***	1.000

* p <10%; ** p < 5%; *** p < 1%

Source: Authors' calculations

According to Table 2, the variables of internet accessibility, the interaction between internet accessibility and innovative activities, the economic development, the trade openness, and the ratio of foreign direct investments to GDP are positively correlated with CO_2 emissions at the 1% significance level. In contrast, innovative activities are inversely associated with CO_2 emissions at the 1% significance level.

4.2. Model results

The testing and regression results of the models shown in Table 3 indicate that their significance levels are all less than 1%, implying statistical significance. These results show that both the data and models are suitable. The Hausman test is not statistically significant at the 10% level when comparing random-effect and fixed-effect estimates, suggesting that the random-effect model is the best fit.

In addition, the result of the Wooldridge test is statistically significant at the 1% significance level, inferring that there is autocorrelation in the models, which can result in inaccurate regression coefficients for the estimation model. Similarly, the p-values of Breusch-Pagan/Cook-Weisberg test and Modified Wald test are less than 1%. Therefore, the authors utilized the Driscoll-Kraay model to address estimation issues. The specific results are as follows:

Table 3. Role of innovation in regulating the impacts of internet use on CO_2 emissions

Variables	$CO_{2i,t}$					
	Random effects	**Driscoll-Kraay**	**Random effects**	**Driscoll-Kraay**	**Random effects**	**Driscoll-Kraay**
$PAT_{i,t-1}$	-0.0005*** (0.00004)	-0.0005*** (0.00008)	-	-	-0.0002*** (0.00008)	-0.0002*** (0.00007)
$IU_{i,t-1}$	-	-	0.0226*** (0.0033)	0.0226*** (0.0029)	0.0782*** (0.0139)	0.0782*** (0.0186)
$PAT*IU_{i,t-1}$	-	-	-	-	-0.000005*** (0.000001)	-0.000005** (0.000001)
$LGPP_{i,t-1}$	-		-	-	2.4118*** (0.4988)	2.4118*** (0.4254)
$TO_{i,t-1}$	-		-	-	-0.01*** (0.00303)	-0.01** (0.00455)
$FDI_{i,t-1}$	-		-	-	-0.0208 (0.03823)	-0.0208 (0.0378)

Constant	3.2034*** (0.6719)	3.1978*** (0.3176)	-1.0158 (1.7734)	-1.0158** (0.4129)	-14.308*** (3.7614)	-15.102*** (3.5234)
Number of groups	7	7	7	7	7	7
Number of observations	170	170	170	170	170	170
Year	Yes	Yes	Yes	Yes	Yes	Yes
Income	Yes	Yes	Yes	Yes	Yes	Yes
Hausman test	29.41 [0.3413]					
Wooldridge test	26.76*** [0.002]					

* p <10%; ** p < 5%; *** p < 1%

Source: Authors' calculations

The analysis using the random-effects method in Table 3 shows that the CO_2 emissions of some Southeast Asian countries are negatively proportional to trade openness, the interaction between innovation and internet use, and innovative activities at the 1% significance levels. In contrast, the study results show that there is a positive correlation between internet use and economic development at the 1% significance level.

4.3. Robustness test

To ensure a robust estimate of the research model, we used the variable PATP to replace the variable PAT. The estimation results are as follows:

Table 4. Robustness test

Variables	$CO_{2i,t}$					
	Random effects	**Driscoll-Kraay**	**Random effects**	**Driscoll-Kraay**	**Random effects**	**Driscoll-Kraay**
$PATP_{i,t-1}$	-3.2356*** (0.2555)	-3.2356*** (0.6493)	-1.6281*** (0.3267)	-1.6281*** (0.525)	-0.7908* (0.4153)	-0.7908** (0.314)
$IU_{i,t-1}$	-	-	0.0814*** (0.008)	0.0814*** (0.0105)	0.0974*** (0.0094)	0.0974*** (0.007)
$PATP*IU_{i,t-1}$	-	-	-0.0425*** (0.0051)	-0.0425*** (0.0121)	-0.0463*** (0.0054)	-0.0463*** (0.0089)
$LGPP_{i,t-1}$	-	-	-	-	1.4653*** (0.3478)	1.4653*** (0.2372)
$TO_{i,t-1}$	-	-	-	-	-0.009*** (0.002)	-0.009** (0.003)
$FDI_{i,t-1}$	-	-	-	-	-0.0417 (0.0307)	-0.0417 (0.044)
Constant	1.9137*** (0.6273)	1.3108*** (0.0841)	-1.9038*** (0.4836)	-0.8148* (0.4355)	-8.3246*** (2.6382)	-12.538*** (1.6292)
Number of groups	7	7	7	7	7	7
Number of observations	170	170	170	170	170	170
Year	Yes	Yes	Yes	Yes	Yes	Yes
Income	Yes	Yes	Yes	Yes	Yes	Yes

* p <10%; ** p < 5%; *** p < 1%

Source: Authors' calculations

Table 4 shows that the variable PATP has a negative effect on CO_2 emissions at 1% significance level. It suggested that a reduction in CO_2 emissions is a result of the amount of patent applications per capita. Besides, the interaction variable between PATP and IU has a negative effect on CO_2 emissions at 1% significance level. It is consistent with the estimated result in Table 3. Therefore, we can affirm that innovative activities play the role in reducing the negative impact of the internet on environmental quality in Southeast Asian countries.

4.4. Discussion

There is a negative correlation between innovation and CO_2 emissions of some Southeast Asian countries at the 1% significance level. Therefore, the authors had sufficient evidence to accept the hypothesis H_1, which indicates that innovation can make contributions to reducing the CO_2 emissions of several Southeast Asian countries. This study›s findings are consistent with those of Dauda et al. (2019), Chen and Lee (2020), and Nguyen (2021). The results of this study also imply that several Southeast Asian countries are implementing policies encouraging innovation to improve productivity and to replace fossil fuels with more environmentally friendly energy sources.

The findings also support the hypothesis H2, which contends that rising internet use will increase CO2 emissions in some Southeast Asian countries, since there is a positive correlation between internet usage and CO2 emissions in some Southeast Asian countries at the 1% significance level. The study's results, which concur with those of Salahuddin et al. (2016), can be explained by the fact that domestic energy demand rises as a result of rising internet usage. Additionally, Southeast Asian countries still use a lot of fossil fuels, which has an adverse effect on the environment.

The interaction between innovation and internet use is negatively associated with CO_2 emissions of some Southeast Asian countries at the 5% significance level. Therefore, the hypothesis H3 is accepted. It suggests that internet use, when being moderated by innovation, has negative impacts on CO_2 emissions in some Southeast Asian countries. The results of this study can be explained by the fact that a country's high internet access can accelerate the transition of traditional commercial activities to online activities as well as the digital transformation, which can increase innovative activities and, in turn, reduce CO2 emissions indirectly. However, the impact of the interaction between innovation activities and internet access on CO_2 emissions is very low (-0.000005), implying that the growth of innovation has not benefited from the rapid growth in internet usage to reduce CO_2 emission in Southeast Asian countries.

5. Conclusion

Currently, more governments are concerned about the environmental damage caused by CO_2 emissions. Although numerous studies have demonstrated the impact of innovation on CO_2 emissions, almost no research has examined the role of innovation in regulating the effects of internet use on CO_2 emissions. Therefore, additional research is required to determine whether innovation moderates the effect of internet use on Southeast Asian countries' CO_2 emissions. The purpose of this study is to investigate the role of innovation in moderating the impacts of internet use on CO_2 emissions in seven Southeast Asian countries from 1996 to 2020.

The findings reveal a direct correlation between internet use and CO_2 emissions in certain Southeast Asian nations. Nonetheless, innovation can mitigate the impact of internet use on CO_2 emissions, albeit to a small degree. The study results suggest that Southeast Asian countries should adopt policies that make effective use of the internet›s rapid expansion to reduce CO_2 emissions. In addition, there should be policies that facilitate the investments of foreign businesses in new technologies and transitions to cleaner and more environmentally friendly fuel sources, thereby reducing CO_2 emissions.

Our paper has some contributions, but there are still some limitations that need to be improved. First, our study employed the number of patent applications as a measure of innovation activity. In order to gain a deeper understanding of the relationship between the internet and innovation, future research may consider utilizing a variety of indicators, such as research and development expenditure. In addition, the sample size is limited. Therefore, future studies may expand the study’s scope in order to evaluate the accuracy and efficiency of statistical estimations.

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